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Summary of National and International Fuel Cycle and Radioactive Waste Management Programs: 1984

K. M. Harmon
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July 1984

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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SUMMARY OF NATIONAL AND INTERNATIONAL FUEL CYCLE AND RADIOACTIVE WASTE MANAGEMENT PROGRAMS: 1984

K. M. Harmon
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Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

The United States has a national commitment to cooperate with other nations in developing nuclear power technology. This policy is implemented in the waste management field in several ways:

- Collaboration in bilateral or multinational projects
- Technical exchanges between experts, under bilateral cooperative agreements with other countries and the European Community
- Participation in the work of the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA)
- Transfer of technology by publication of government reports
- Commercial trade.

The United States also has a national commitment, expressed in the Nuclear Waste Policy Act of 1982, to offer assistance to nonweapons nuclear nations in their search for solutions to their spent fuel management problems.

Since late 1976, Battelle staff members at the Pacific Northwest Laboratory have been working under U.S. Department of Energy (DOE) sponsorship to assemble and consolidate openly available information on foreign and international nuclear waste management programs and technology, providing an information base for DOE's international technology exchange programs. This report summarizes the collected information on the status of fuel cycle and waste management programs in countries making major efforts in these fields as of the end of May 1984. The report is limited to fuel cycle and waste management activities for civilian nuclear power programs. The sources of information vary extensively and include the proceedings of international symposia and conferences, papers presented at technical society meetings, topical reports, contacts with foreign experts, and the news media. When information from source to source is inconsistent, but within reasonable bounds, approximations are presented. References are provided only for the major sources.

SUMMARY

Worldwide activities related to nuclear fuel cycle and radioactive waste management programs are summarized, with a review of the programs and plans of the following nations:

- Argentina
- Australia
- Belgium
- Brazil
- Canada
- China (People's Republic)
- Denmark
- Finland
- France
- Germany (FRG)
- India
- Italy
- Japan
- Korea (ROK)
- Mexico
- Netherlands
- Pakistan
- South Africa
- Spain
- Sweden
- Switzerland
- Taiwan Republic of China
- United Kingdom
- United States
- USSR and the other nations in the Council for Mutual Economic Assistance

Fuel cycle activities vary greatly from country to country: some nations have chosen a closed fuel cycle, with reprocessing of spent fuel and recycle of the plutonium to breeder or thermal reactors; others regard the spent fuel as a waste and plan direct disposal after an interim storage period of 10 to 100 years. Some nations have achieved complete domestic independence with regard to their fuel cycle operations; others depend upon foreign fuel cycle services. All nations face the problem of conditioning and disposing of radioactive waste from reactor research and medical facilities, and nearly all must dispose of either spent fuel or reprocessing waste.

Several trends have developed in waste management strategy:

- All countries having to dispose of reprocessing wastes plan on conversion of the high-level waste (HLW) stream to a borosilicate glass and eventual emplacement of the glass "logs," suitably packaged, in a deep geologic repository.
- Countries that must deal with plutonium-contaminated waste emphasize plutonium recovery, volume reduction and fixation in cement or bitumen in their treatment plans and expect to use deep geologic repositories for final disposal.

- Commercially available, classical engineering processes are being used worldwide to treat and immobilize low- and intermediate-level wastes (LLW, ILW); disposal to surface structures, shallow-land burial and deep-underground repositories, such as played-out mines, is being done widely with no obvious technical problems. Nevertheless, many nations see disposal of LLW/ILW as their most pressing waste management problem--principally because of the waste volumes involved and the difficulties faced in siting disposal facilities.

Many countries have established extensive programs to prepare for construction and operation of geologic repositories. To summarize:

- Geologic media being studied fall into three main classes: argillites (clay or shale); crystalline rock (granite, basalt, gneiss or gabbro); and evaporates (salt formations). Many of the countries have selected a specific medium for top-priority attention and are proceeding to identify and characterize potential repository sites; others have yet to make such a selection. A few countries are maintaining a low-priority effort on potential alternatives to their preferred rock types.
- Most nations plan to allow 30 years or longer between discharge of fuel from the reactor and emplacement of HLW or spent fuel in a repository to permit thermal and radioactive decay. In general, national authorities have judged that both spent fuel and vitrified HLW can be stored safely in interim facilities for 50 years or longer.
- Most repository designs are based on the mined-gallery concept, placing waste or spent fuel packages into shallow holes in the floor of the gallery. Retrievability is required in a few cases.
- Many countries have established extensive and costly programs of site evaluation, repository development and safety assessment.

Two other waste management problems are the subject of major R&D programs in several countries: stabilization of uranium mill tailing piles; and immobilization or disposal of contaminated nuclear facilities, namely reactors, fuel cycle plants and R&D laboratories.

CONTENTS

FIGURE

TABLES

ACRONYMS[a] AND ABBREVIATIONS

AFR	Away-From-Reactor
AVM	Waste Vitrification Plant at Marcoule, France
BLWR	H_2O-Cooled D_2O-Moderated, Boiling Water Reactor
BWR	Boiling Water Reactor
CANDU	Canadian Deuterium Uranium Reactor
FBR	Fast Breeder Reactor
FINGAL/HARVEST	British Waste Vitrification Process
FIPS	West German Process for Vitrifying High-Level Waste, Developed at Jülich
FRP	Fuel Reprocessing Plant
GCHWR	Gas-Cooled, Heavy Water Reactor
GCR	Gas-Cooled Reactor
GWe	10^9 Watts of Electricity (1000 MWe)
HFR	High Flux Reactor at Petten, Netherlands
HLLW	High-Level Liquid Waste
HLW	High-Level Waste
HTGR	High-Temperature, Gas-Cooled Reactor
HTR	High-Temperature Reactor
HWLWR	Heavy Water-Moderated, Light Water-Cooled Reactor (same as LWCHW)
HWR	Heavy Water Reactor
ILW	Intermediate-Level Waste
LGR	Light Water-Cooled, Graphite-Moderated Reactor
LLW	Low-Level Waste
LMFBR	Liquid Metal Fast Breeder Reactor
LWCHW	Light Water-Cooled, Heavy Water-Moderated Reactor (same as HWLWR)
LWR	Light Water Reactor
MOX	PuO_2-UO_2 Fuel
Mtoe	Metric tons of oil equivalent
MTR	Materials Test Reactor

(a) Acronyms for agencies, institutes, etc. are given in the Overview section for each country.

PAMELA	West German and Eurochemic Process for Converting High-Level Waste to Glass Beads and Embedding Them in a Metal Alloy
PFR	Prototype Fast Reactor (UK)
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor
R&D	Research and Development
SS	Stainless Steel
tHM	Metric Tons (tonnes) Heavy Metal
THTR	Thorium High-Temperature Reactor
TRU	Transuranic
tSWU	Metric Tons of Separative Work (Uranium Enrichment)
tU	Metric Tons Uranium
TWh	Terawatt Hour (1 million kilowatt hours)
WAK	Fuel reprocessing pilot plant near Karlsruhe

INTRODUCTION

Currently 34 nations have nuclear power stations operating, under construction, or reasonably well committed for commissioning by the year 2000. Except for a few demonstration reactors burning specialized fuel, these power stations are fueled with natural or slightly enriched UO_2 clad in Zircaloy, UO_2 clad in stainless steel or uranium metal clad in a magnesium or aluminum alloy.

The fuel cycle scheme varies from country to country. Some nations are already committed to a closed fuel cycle which includes interim storage of spent (irradiated) fuel in a water basin until the short-lived radioactive fission products have decayed; reprocessing to recover plutonium and uranium; recycle of plutonium and uranium to an appropriate nuclear power reactor system; and immobilization, interim storage and disposal of the fuel cycle waste. Some nations regard the spent fuel as waste, hence plan direct disposal following an interim storage period of 10 to 100 years. In many cases the fuel is stored retrievably until a final decision can be made between the once-through and reprocessing schemes and the necessary facilities are in place.

The scope of the fuel cycle effort in each country depends on a number of factors, e.g., national policy concerning nuclear weapons production capability, self-sufficiency in the nuclear-power field and development of breeder reactors; the magnitude of the thermal power reactor program; the extent of the country's industrial/institutional use of radioisotopes; and the level of scientific and industrial activity in the country.

Nearly every nation with nuclear power capability, or aspirations towards it, has a waste management program. The effort in some countries is limited to research on treating low-level waste from reactor plant operations. In other countries, advanced technology is being developed for all waste management operations and a major effort at commercialization exists.

International usage now recognizes the following categories of radioactive waste:

- High-level waste. Arising as the waste stream from the first extraction cycle of a spent fuel reprocessing plant, HLW contains transuranic elements as well as fission products and is highly radioactive, heat-generating and long-lived.
- Transuranic waste (TRU). This category includes waste, except spent fuel and HLW, contaminated highly enough with long-lived, alpha-emitting nuclides to make disposal in an engineered storage structure or a shallow-land burial site unacceptable. TRU waste arises principally from spent fuel reprocessing and UO_2-PuO_2 (MOX) fuel fabrication.
- Low- and intermediate-level waste. This waste category is contaminated with radionuclides having half-lives no longer than 50 years. (Traces of transuranics may be present, but TRU content is low enough to avoid classification as TRU waste.) It arises from varied sources and includes very diverse materials, e.g., reactor waste, including resins from water purification systems; slightly-contaminated liquid waste from reprocessing plants; miscellaneous waste from plant operations; etc.
- Airborne waste. These materials most commonly arise from reprocessing plant off-gas treatment systems and may be contaminated with tritium, carbon-14, krypton or radio-iodine. They are often classed as LLW/ILW.
- Uranium mine and mill tailings. Arising from mining and ore processing operations, these wastes are very large in volume and contaminated with naturally-occurring radionulides.
- Surplus nuclear facilities--fuel cycle plants, nuclear power plants, research facilities, etc.

This report summarizes the back-end-of-the-fuel-cycle activities of those nations known to be working in this field. Emphasis is placed on management of spent fuel and on HLW conditioning and disposal programs. The treatment and disposal of TRU waste and LLW/ILW is also reported for those countries which have major programs in these areas. Several summary tables are provided in the Appendix.

The report also reviews briefly the radioactive waste management activities of four international agencies--the Commission of the European Communities (CEC), the Council for Mutual Economic Assistance (CMEA), the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD).

ARGENTINA

Argentina has two PHWRs in operation and has five more on order or under construction. Major nuclear objectives are to develop a strong, self-sufficient nuclear power industry, based on the CANDU-type PHWR and heavy water-natural uranium fuel cycle, and to become the supplier of reactor plants and fuel cycle services to Latin American and other less-developed countries.

ELECTRIC POWER DATA

Electricity Production

1981: 35.3 TWh--50% fossil fuels; 42% hydro; 8% nuclear.(1)

Nuclear Power[a]

First operating power plant: 335 MWe PHWR (1974)

Projection: 1984--0.9 GWe; 1990--1.6 GWe; 2000--3.0 GWe.

ORGANIZATION

The Comisión National de Energía Atomica (CNEA--National Atomic Energy Commission), Buenos Aires, owns and operates all facilities, including the Ezeiza Atomic Centre, located about 10 miles northwest of Buenos Aires.

NUCLEAR FUEL CYCLE

Fuel Production

Argentina has reasonably assured uranium reserves of about 30,000 tU and uranium milling capacity of 200 tU_3O_8 per year.[b] A commercial gaseous diffusion uranium enrichment plant is being built, with a planned capacity of 500 kg/yr of 20% enriched uranium and a projected completion date of 1985.

The government has two UO_2 conversion lines and a new UO_2 fuel and Zircaloy tubing fabrication plant at Ezeiza. The first fabrication line

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(a) Unless an alternative reference is given, nuclear power data in this and following sections are derived from References 2 and 3.

(b) Uranium resources and production data in this and following sections are taken from Reference 4.

started up in April 1982. When the plant reaches full capacity (1987), it will produce 33 t/yr Zircaloy and 300 t/yr uranium.

Spent Fuel Management(a)

Spent fuel pool storage is provided at the reactor (AR), and away-from-the-reactor (AFR) storage may be required. The fuel is to be cooled for about 10 years after discharge from the reactor and before reprocessing; consideration has been given to interim storage in the HLW repository.

Reprocessing

Argentina operated a small experimental reprocessing facility from 1967 through the early 1970s, and a new pilot reprocessing facility is under construction at Ezeiza. This 20 kg/day plant is scheduled to be ready for cold-testing in 1985 and hot-operation in 1987. A new plant is also being designed, with a nominal capacity for HWR fuels of 40 t/yr. It is to be located near the pilot facility and will be part of a complex equipped for spent fuel storage, conversion of uranium and plutonium to oxides, and treatment of waste.

WASTE MANAGEMENT

Waste Treatment

A pot vitrification process (evaporation, calcination and glass forming in the storage canister) is being developed for HLW from reprocessing operations. Current package designs envisage stainless steel canisters overpacked with 10 cm of lead and another metal sheath. Waste content in the glass (fission product and transuranic oxides) has been set at 10%.(7) Reactor and laboratory waste is treated at the Ezeiza Center by standard techniques: filtration and evaporation of liquids; incineration or compaction of low-level solids; acid digestion of combustible transuranic waste; and immobilization in bitumen or cement.

(a) Spent fuel storage and reprocessing information in this report is abstracted from References 5 and 6, respectively.

Waste Disposal

Solid wastes containing radionuclides with half-lives less than five years are disposed of by shallow-land burial, while longer-lived materials are buried in concrete cubicles.

Studies on the selection of a site for a geologic repository for HL and transuranic waste started in 1980. Two hundred granite intrusions, distributed throughout the country, were identified. The list was narrowed to four sites which met these criteria: no potential mineral interest, location outside seismic zones, and low hydraulic conductivity. Site characterization efforts are now concentrated on a location in the Sierra del Medio, near Gastre in the province of Chubut. Site characterization, including the drilling of wells to depths of 200-600 m, is to be completed in 1984. The repository design concept calls for the waste containers to be placed upright in shafts dug in the floor of the galleries at a depth (below grade) of about 500 m. The shafts are to be 1 m in diameter and about 4.5 m deep. With a waste content of 10% and a decay time of 20 years after fuel discharge from the reactors, the thermal output from each HLW canister will be 500 watts at the time of placement in a repository.(7)

AUSTRALIA

Even though Australia is a major uranium producer, no commitment has been made to nuclear power plant construction. For about two decades, starting in the early 1950s, government planners assumed that nuclear power would be introduced in the country and maintained a reactor development program. In the early 1970s, this effort was scaled down and the resources, diverted from reactor studies, were applied to the front end of the fuel cycle (uranium extraction, conversion and enrichment). Currently, the national nuclear research and development program is focused on: limited support of reactor operations research; solution of environmental problems associated with uranium mining and milling; work on applications for radioisotopes; development of Australia's SYNROC process for immobilizing HLW; and studies of new energy technologies such as fusion.

ORGANIZATION

The Australian Atomic Energy Commission (AAEC) is an agency of the Ministry of State for Resources and Energy. Nuclear research and development is carried out mainly at the AAEC Research Establishment, Lucas Heights, in Sutherland, New South Wales (near Sydney) with contributions from some of the universities.

NUCLEAR FUEL CYCLE

Uranium Production

The country's reasonably assured uranium resources are estimated at 336,000 tU. Before the present government came into power in 1983, uranium mining and milling was expected to reach levels of 12,000 t/yr U_3O_8 by 1986 and 15,000 t/yr by 1990. The new government, however, has taken an anti-uranium-mining position and severely restricted mining activities.

In efforts to expand the Australian uranium industry, the AAEC conducted feasibility studies on the manufacture of UF_6 and on commercial enrichment of uranium by gas centrifuge or laser technology. Exploratory talks were also held with several organizations in other countries looking toward a potential cooperative uranium enrichment venture.

WASTE MANAGEMENT

High-Level Waste Immobilization(8)

Australia has no plans for commercial spent fuel reprocessing, but the government is sponsoring the development of the SYNROC process for immobilizing the radionuclides in high-level waste.

The SYNROC process produces a mixture of synthetic mineral phases characterized by two key properties: great geochemical stability and the ability to incorporate into solid solution all the important radionuclides present in the waste. Basic SYNROC ingredients are TiO_2, ZrO_2, Al_2O_3, CaO, BaO and the waste calcine. The reaction of the ingredients to form the synthetic mineral phases, and fabrication of the waste form can be accomplished by some form of solid state process, such as hot-pressing or sintering. The first engineering-scale demonstration was achieved at Lucas Heights in November 1981.

SYNROC studies are continuing at the Australian National University, Canberra, with the emphasis on process basics, and at the Lucas Heights Laboratory, where the focus is on process scale-up. Lucas Heights activities include:

- Design and construction of a nonradioactive pilot plant. The plant, due to be commissioned in 1985-6, will have a rated capacity of 20 kg SYNROC per hour and demonstrate the fabrication of SYNROC-filled canisters of up to 400 mm internal diameter. It will be engineered to avoid any procedures incompatible with remote operation, highly instrumented and partly automated. Investigators believe that the SYNROC waste form for HLW from light-water reactors (LWR) can handle waste loadings as high as 20%.
- Operation of a glove box line to produce SYNROC (containing actinides and ^{99}Tc) on a hundreds-of-grams scale.
- Small-scale hot-cell processing line.

Geologic Waste Isolation

Australia has large ore bodies located near the surface in areas subject to high seasonal rainfall and periodic flooding. Past movement of radionuclides (^{238}U, ^{234}U, and ^{230}Th) under these conditions is being analyzed by AAEC to provide a basis for the construction of a model of radionuclide movement through clay over a time span of about one-half million years.

In other studies related to geologic waste isolation, Australian investigators are measuring leach rates for various SYNROC compositions and for other waste forms under actual and postulated repository conditions.

Mine and Mill Tailing Management(9,10)

The AAEC program on management of mine and mill tailings includes development of technology for control of radon and radium, site characterization and rehabilitation, and decommissioning of one site (Mary Kathleen). Studies on control of radon and radium have been made to determine factors affecting leaching of tailings, to assess the feasibility of chemically extracting radium from tailings, and to examine methods of removing radon from air streams. Except in the case of one site controlled by the Commonwealth Government, regulation of mining activities is performed by the state governments. Control practices vary from site to site but have two common objectives--to minimize the release of radionuclides and to achieve a "walk-away" condition at the site after decommissioning. A major decommissioning program, costing 10-20 million dollars, is underway at the Mary Kathleen site in Northwest Queensland.

BELGIUM

Belgium has five PWRs in operation and two under construction. The utilities have requested approval for two new 1.3-GWe nuclear plants, but the government has deferred a decision, pending results of negotiations with France over Belgian participation in two 1050-MWe plants which France proposes to build at Chooz, near the French-Belgian border. The country is also achieving fast breeder reactor (FBR) capability through participation in the Kalkar SNR-300 project in West Germany.

Government and utilities are working toward well-rounded fuel cycle capability through participation in the Eurodif enrichment plant in France, development of MOX fuel fabrication, waste treatment and geologic waste disposal facilities, and takeover and operation of Eurochemic fuel reprocessing and waste treatment plants.

ELECTRIC POWER DATA

Electricity Production(a)

1981: 50.8 TWh--45% oil/gas, 25% solid fuels, 25% nuclear, 2% hydro
1986: 60% nuclear.

(a) Electricity production data for OECD countries are taken from Reference 11.

Nuclear Power

First operating power plant: 390 MWe PWR (1975)
Projection: 1984--3.5 GWe; 1990--5.4 GWe; 2000--8.0 GWe.(1)

ORGANIZATION

The following organizations have major responsibilities for the back end of the fuel cycle: the Centre d'Etude de l'Energie Nucléaire (CEN/SCK), the national nuclear research institute, at Mol; the National Institute for the Treatment of Radioactive Waste (ONDRAF), organized by the government in 1981 as the national waste management company; SYNATOM S.A., with mixed private and government ownership and responsibility to provide nuclear fuel cycle services; and Belgonucleáire S.A., owned partly by CEN/SCK (50%) and partly by private interests, MOX fuel manufacture.

A new company is expected to be formed to refurbish and operate the Eurochemic Reprocessing Plant at Mol, with ownership vested partly in the government and partly in private interests.

NUCLEAR FUEL CYCLE

Fuel Production

Belgium has no domestic uranium resources, hence is fully dependent on foreign sources. Enrichment services are obtained from the USSR, the US and Eurodif, the international enrichment company in which Belgium holds an 11% interest.

Nuclear fuel fabrication capability is provided by Belgonucléaire and the Societé Franco-Belge de Fabrication de Combustibles (FBFC), both having plants located in Dessel, near Mol. The Belgonucléaire plant has the capacity to fabricate 18 t/yr of PuD_2-UD_2 fuel for use in LWRs and is also designed to permit the fabrication of test reactor fuel.

Spent Fuel Reprocessing

The Eurochemic plant at Mol, with a capacity of 0.3 tHM/day for low-enriched uranium fuels, operated from 1966 to 1974. During this period, it processed about 100 t of slightly-enriched LWR fuel, 80 t of natural-uranium fuel and 30 t of highly-enriched uranium fuel from research reactors. The plant has been decontaminated(12) and may be refurbished to resume operation under Belgian ownership. In the meantime, part of Belgium's spent fuel is being treated in foreign plants.

In a separate effort, CEN/SCK is operating a small headend pilot plant (HERMES). This hot-cell complex can handle 10-kg batches of LMFBR fuel and is used to test a fuel chopper, a critically-safe dissolver and off-gas treatment systems.

WASTE MANAGEMENT

Waste Treatment

Liquid LLW from Belgian nuclear power plants is treated at the reactor site, immobilized in concrete, and shipped to CEN/SCK for disposal. Solid LLW is shipped to Mol for incineration or immobilizing in bitumen or concrete. CEN/SCK has placed in operation a high-temperature (>1,400°C) slagging incinerator that has handled low-level reactor waste and has been tested successfully with Pu-contaminated waste.(13)

Operation of the Eurochemic reprocessing plant produced nearly 900 m^3 of concentrated HLW, still stored at the site. Following the 1971 decision to close the plant in 1974, the Eurochemic Company agreed to take responsibility for converting the plant's HLW to a form which could be safely stored, pending decision as to final disposal. After several years' work on various HLW immobilization techniques by the Eurochemic staff, company directors decided to build an AVM-type vitrification plant (AVB) at Mol. Construction, however, depends on a final decision concerning resumption of the reprocessing plant operations. If the reprocessing plant is left dormant, all existing HLW will probably be vitrified in a German pilot plant (PAMELA), currently being built at Mol (see Section on FRG).

Eurochemic has installed several facilities for treatment and storage of low- and intermediate-level waste from the reprocessing plant: Eurobitum, a 650-m^3/yr bituminization plant; Eurostorage, for storage of conditioned waste;

and Eurowatt, a pilot facility for treating waste PUREX solvent. Eurochemic is also the site of ALONA, an acid digestion plant for combustible TRU waste, built and operated by Germany's Karlsruhe Nuclear Research Center.(14)

Waste Disposal(15,16)

The following management scenario is envisaged for high-level waste: five-year liquid storage; vitrification; 50-year minimum interim solid storage; and transfer to an underground repository.

A study of the use of deep geological formations in shale and clay deposits for the disposal of solid radioactive waste was begun in 1974. As a result of these studies, authorities decided to focus their efforts on constructing a repository in one of Belgium's plastic clay formations. A joint CEN/SCK-Euratom project was initiated to build an underground laboratory in the Boom clay formation which underlies the Mol area.

The initial effort was to build a shaft and horizontal experimental gallery, the latter at the 190-m depth. The gallery will be used for pressure measurements within the clay bed, for corrosion studies and for other investigations of the Boom clay properties. Construction started in 1981 and was completed in late 1983. Preparations are now being made to extend the program to include the test emplacement of high-level waste and plutonium-bearing incinerator residues.

For many years, under the supervision of the OECD/NEA, low-plutonium waste meeting the international sea-dump criteria was dropped into the Atlantic at depths of about 4000 m. These sea-dumping activities ended, at least temporarily, in 1983. Their resumption will depend on the results of current NEA, IAEA and IMO studies on the safety of sea-disposal of radioactive waste.

BRAZIL

Brazil has one PWR in operation and two under construction. Major objectives of the nuclear program are to continue expansion of LWR power production capacity, introduce FBRs and develop complete LWR and LWR fuel cycle independence.

ELECTRIC POWER DATA

Electricity Production

1980: 125 TWh--88% hydro, 8% nuclear, 4% thermal

Nuclear Power

First operating power plant: 626 MWe PWR (1984)
Projection: 1990--1.9 GWe; 2000--4.4 GWe.

ORGANIZATION

Nuclear power policy and R&D programs are planned, executed, and controlled through the Ministry of Mines and Energy. Directly subject to the Ministry is the National Nuclear Energy Commission (CNEN), which performs regulatory, licensing, planning, surveillance, safety evaluation, and operator training functions. Nuclebrás, a federal nuclear power enterprise, is responsible for plant engineering, project preparation, civil construction, and equipment erection for fuel cycle facilities. Facilities are at Rio de Janeiro (headquarters; design and construction components), Resende (uranium conversion and enrichment; fuel fabrication; reprocessing), Belo Horizonte (Center for Development of Nuclear Technology, CDTN; enrichment pilot plant), and Pocos de Caldas (mining and milling).

CNEN fuel cycle R&D is conducted at the Energy and Nuclear Research Institute (IPEN) of the University of Sao Paulo.

NUCLEAR FUEL CYCLE(17)

Fuel Production

Reasonably assured uranium reserves in Brazil are estimated at about 155,000 t. Production of yellowcake was initiated in the Spring of 1982 at the Pocos de Caldas complex in the state of Minas Gerais and is expected to reach a rate of 420 tU/yr.

At present, Brazilian yellowcake is shipped to France for conversion to UF_6 and then sent to the United Kingdom for enrichment. The enriched UF_6 goes to West Germany for manufacture of pellets, which are returned to Brazil for fabrication of fuel pins and assemblies. In the drive to be self-sufficient in the fuel cycle, Nuclebrás is building pilot plants or industrial-scale facilities for production of UF_6, uranium enrichment and spent fuel reprocessing.

Spent Fuel Reprocessing

Design for a proposed pilot fuel reprocessing plant was completed in 1981 and the plans submitted to CNEN for safety review. Reports indicate, the pilot plant will be located in the Rio de Janeiro area, perhaps at Resende; it will have a 10 kg/d design capacity and will be the forerunner of a 300 t/yr industrial-scale facility.

WASTE MANAGEMENT

Brazil's waste management R&D program has received little publicity. Consideration is apparently being given to several possible sites: deserted islands off the coast of Brazil, and the Pocos de Caldas uranium mine, once the uranium reserves have been removed.

CANADA

Canada has 13 PHWRs and 1 BLWR in operation and 10 PHWRs under construction, all but three of them in Ontario Province. The PHWRs use the Canada deuterium uranium (CANDU) PHWR system, which burns natural uranium UO_2 fuel and is both cooled and moderated with heavy water.

The government strongly supports the nation's nuclear program, developed exclusively around domestic suppliers. The nation has an active, close-knit fuel cycle and waste disposal program. Virtually all decisions concerning R&D, policy and implementation are made by the government or Atomic Energy of Canada Limited and appear directed toward evolution of the CANDU reactor system and reservation of uranium for national needs.

ELECTRIC POWER DATA

Electricity Production

1981: 383.6 TWh--69% hydro, 16% solid fuels, 10% nuclear, 5% gas/oil.

Nuclear Power

First operating power plant: 206 MWe PHWR (1968)
Projection: 1984--8.8 GWe; 1990--13.4 GWe; 2000--14.9 GWe.

ORGANIZATION

Commercial nuclear power activities in Canada are handled primarily by two organizations: Atomic Energy of Canada Limited (AECL), a "Crown Corporation" owned by the national government, and Ontario Hydro, the provincial utility which owns and operates most of Canada's nuclear power reactors. AECL designs and engineers CANDU reactors for domestic and export markets, handles construction and project management related to CANDU exports, operates Canada's heavy water plants, and manages and performs most of the country's nuclear research and development. Regulatory matters are handled by the Atomic Energy Control Board (AECB).

The Canadian fuel cycle and waste management R&D program involves a number of government agencies and universities, principally: AECL's Whiteshell Nuclear Research Establishment (WNRE), which coordinates the "spent fuel waste" management program; Ontario Hydro, which directs and funds storage and transportation R&D and contributes to the work on waste immobilization and disposal; AECL's Chalk River Nuclear Laboratories, which have the reactor waste management assignment, and CANMET, which has the mine/mill tailings studies.

NUCLEAR FUEL CYCLE

Canada's CANDU reactors are fueled with natural uranium. Although their fuel is discharged after relatively low burnup, Canada has sufficient uranium reserves to continue operating its reactors without fuel recycle well into the next century, and there has been little incentive as yet to reprocess spent fuels. A decision to recover plutonium, however, is possible in the future and

AECL may turn to a Th-^{233}U fuel cycle. Hence the spent fuel waste program is preparing to dispose of either CANDU UO_2 fuels or reprocessing waste.(18)

Fuel Production

Canada has reasonably assured uranium reserves, estimated at 185,000 tU and expects to increase its uranium mining and milling capacity to 11,500 tU/yr by 1985. The CANDU reactor system does not use enriched uranium, but D_2O is required, and the country has heavy water facilities as well as CANDU fuel manufacturing plants.

Spent Fuel Management

Current spent fuel management strategy is to depend on AR storage until reprocessing or spent fuel disposal facilities are established. Also, in case the choice between reprocessing and fuel disposal is deferred for many years, concepts for the dry storage of spent fuel for extended periods (>50 years) are being evaluated.(19) Whiteshell has a laboratory-scale reprocessing R&D program in place to support the reprocessing option.

WASTE MANAGEMENT

Waste Treatment

Ontario Hydro and the Chalk River Laboratories have studied and applied a variety of techniques for treatment of reactor waste: incineration, acid digestion, and mechanical compaction. Bituminization of incinerator ash, ion exchange resins and aqueous waste slurries are being tested at Chalk River. Conditioned reactor waste from Ontario Hydro operations is stored at the Bruce power station in engineered structures designed to allow retrievability.(20)

Preparing for the possibility that Canada will need to immobilize HLW, Whiteshell has assembled the inactive "Waste Immobilization Process Experiment" (WIPE). The facility consists of a rotospray calciner and ceramic electromelter, designed to produce 10 kg/hr borosilicate glass. In related work, WNRE is studying alternative HLW forms and the relationships between waste product composition and glass stability.

Waste Disposal

Four operational LLW storage sites are in existence, two on AECL-owned land and two on utility property. LLW from research facilities and from commercial reactors is reduced in volume and shipped to one of these disposal sites for shallow burial or storage.

In 1981 the federal government approved continuation and expansion of Canadian geologic repository studies in a 10-year, spent fuel waste management program, funded initially at $30 million (Canadian dollars) per year. The repository program schedule calls for the research phase to continue until the mid-1980s and concept verification to be completed by 1991. The question, whether or not to construct a demonstration facility, has been left open and emplacement of nuclear waste in a permanent repository is not expected to occur before the year 2010.(18)

The R&D program, coordinated by WNRE, includes: development of canisters for spent fuel to be emplaced in a repository (most of the work to date has been done on providing intact fuel assemblies with a protective shell, designed to prevent collapse of the fuel under geostatic pressures in the repository); studies of those properties of irradiated fuel which determine their performance as a waste form; and development of repository technology.

Many potential sites have been located, primarily in granite formations in Ontario Province, and most of the Canadian geologic disposal effort is applied to granite repository technology. Supporting studies (hydrology, rock mechanics, migration of radionuclides, safety assessment, etc.) are conducted at Whiteshell and by components of the Department of Environment, the Department of Energy, Mines and Resources, and a number of other organizations.(21) Also included in the R&D program are: environmental and safety assessment; construction and operation of the Underground Research Laboratory (URL); and field tests of five research areas each of which encompasses either a segment of a crystalline rock pluton or an entire pluton and some of the surrounding rock.

The URL will be situated in a granite pluton, a few miles from the Whiteshell Center. Shaft-sinking is to begin in 1984, excavation of the gallery in

May 1985, and full operation in 1986. Construction costs are estimated at $19.2 million (Canadian dollars). The laboratory is to be used for basic research and no nuclear waste is to be emplaced at the site. Project objectives are to study: the correlation between surface and subsurface features; hydrogeological and geochemical systems in a plutonic rock; excavation damage in a rock mass; thermal effects; and interactions between a simulated waste package and the surrounding media.(22)

Mine and Mill Tailing Management(23)

With Canada's extensive uranium mining interests, management of the large volumes of residue from mining and milling activities has been the subject of many studies. A five-year, $9.5 million (Canadian dollars) program started in January 1983 to study all long-term issues associated with decommissioning uranium mine/mill tailing facilities.

CHINA (PEOPLE'S REPUBLIC)

China operates nuclear reactors for production of military plutonium and has started to install a generation of PWRs for power production. The nuclear research program is evaluating other proven reactor types--the BWR, FBR and HTGR--and the use of nuclear power as a source of heat for buildings and chemical processes.(24)

ELECTRIC POWER DATA

Electricity Production

1980: 300.6 TWh--approx. 25% hdyro, balance from fossil fuel (0% nuclear).

Nuclear Power

First operating power plant: 300 MWe PWR (1988)

Projection: 1990--2 GWe; 2000--10 GWe.

ORGANIZATION

Nuclear program responsibilities are exercised by the Ministry of the Nuclear Industry (development of nuclear power and nuclear fuel technology), Ministry of Power and Water Resources (construction and operation of nuclear power plants) and several nuclear research institutions.

NUCLEAR FUEL CYCLE

China's current nuclear fuel cycle program, established for weapons production, is well developed on a small scale. China has facilities for uranium conversion, uranium enrichment by gaseous diffusion, fuel element fabrication, and reprocessing of spent fuel from plutonium production reactors in a Purex process plant. Heavy water, zirconium, and other materials are available in small quantities. Studies of reprocessing technology for power fuels are conducted at the Institute of Nuclear Energy Technology, Quinghua University, Peking.

WASTE MANAGEMENT

Chinese scientists have gained experience in nuclear waste disposal through the military production program: high-level and intermediate-level waste is now stored in tanks; low-level waste is discharged after treatment into rivers; gaseous waste is discharged through high stacks after filtration and dilution. R&D is conducted on: HLW vitrification; fixing of ILW in bitumen, cement, or plastics; treatment of LLW containing trans-plutonium elements; recovery of krypton-85; and extraction of fission products and actinides from HLW. HLW vitrification studies were initiated at the Institute of Nuclear Energy Technology, Quinghua University, but have been transferred to another organization, reportedly focusing on using French technology. Development of techniques for treating non-HLW are continuing at the Institute of Nuclear Energy Technology. China has not yet started a serious effort to site a geologic repository. Drums of LLW, generated in the Peking area, are stored in man-made caves in nearby mountains.

CMEA COUNTRIES

The USSR and most of its partners in the Council for Mutual Economic Assistance (CMEA) have joined in a cooperative program to develop a strong, self-sufficient nuclear industry with capability to build nuclear power plants and provide complete fuel cycle services. The USSR's complex of nuclear power stations includes channel-type, light-water cooled, graphite-moderated reactors, PWRs of various sizes, and demonstration LMFBRs. Bulgaria, Cuba, Czechoslovakia, East Germany, Hungary and Poland have chosen to install PWRs developed by the Soviet Union; Yugoslavia, however, is operating a 615-MWe PWR supplied by Westinghouse; and Rumania has turned to Canada for reactor technology and is installing a generation of HWRs.(25,26)

ELECTRIC POWER[a]

Country	Power Production			Nuclear Capacity	
	Year	TWh	% Nuclear	Year	GWe
Bulgaria	1982	29.4	29	1982 2000	1.6 7.6
Cuba				1989	0.85
Czechoslovakia	1982	69	7	1982 2000	0.76 11-14
German Democratic Republic	1982	92	12	1982 1990	1.7 9
Hungary	1981 1986	24	0 24	1983 1986 2000	0.4 1.7 3.5
Poland	1982		0	1990	0.88
Rumania	1982 1992		0 30	1992	6.0
USSR	1982 1985	1,376 1,570	7 14	1982 1990	17.2 60-80
Yugoslavia	1982	62	4	1982 2000	0.6 2.0

(a) Data for 1982 is taken from IAEA report "Status and Trends of Nuclear Power Worldwide," Vienna, 1983; data for other years comes from varied sources.

NUCLEAR FUEL CYCLE

The Soviet Union developed complete fuel cycle capability for its nuclear weapons program and controls most of the nuclear fuel cycle for the CMEA group, providing uranium enrichment, fuel fabrication and spent fuel management services for nuclear plant customers. Following interim storage at reactor sites, spent fuel is returned to the USSR and will eventually be reprocessed to provide plutonium for the nation's FBR program.

Original fuel recycle plans called for spent fuel to be reprocessed three years after discharge from the reactor. The interim storage period in reactor pools, however, is being stretched out to 10 years and construction of a series of AFR storage facilities, each with capacity for the 10-year output of four 440-MWe PWRs (600 tU), is under consideration.(27)

The USSR has been reprocessing military fuels for many years, but has not yet built a reprocessing plant for commercial spent fuels. A 3-kgU/day pilot plant for LWR and FBR fuel began operation in 1973, and authorities reportedly planned to have a 5-tU/day commercial pilot plant on-line by 1980. The plans for commercial reprocessing have apparently been deferred considerably, probably because of delays in breeder reactor development, hence a deferred need for plutonium to fuel their breeders. The Soviets are believed to have reprocessing technology virtually identical to that used in the West, but perhaps not as advanced as Russian authorities would like, particularly with regard to large-scale operations.

WASTE MANAGEMENT

Soviet investigators have developed and tested (pilot plant scale) two processes for HLW vitrification: one produces a phosphate glass; the other, a borosilicate. They are also working on techniques to incorporate waste in glass-crystalline materials and in ceramics. Solidified HLW is to be stored temporarily in a special air-cooled storage facility until the canister can be transferred to a geologic repository.

The geologic repository program involves the evaluation of potential sites in a variety of host rocks--rock salt, clays, granite, gneiss, diabase and porphyrite--and supporting studies of host rock properties.

USSR customers for fuel cycle services do not have to be concerned about disposing of reprocessing waste, since it is to be retained by the Soviet Union. The customers do, however, have the responsibility to treat and dispose of reactor waste and any institutional radioactive waste they may generate.

Available literature, describing the nuclear activities in the CMEA countries, indicates various treatments are employed. Evaporation, ion exchange, and chemical conditioning are widely used to reduce volumes of low-level liquid waste. Bitumen appears to be a common fixation agent employed for liquid concentrates and resins, however, cement is also used with lower activity waste.

As with waste treatment, the CMEA countries are exploring and using several disposal methods. Injection of radioactive liquids into underground strata has been used, but it is uncertain if such practices are continuing. A common practice is storage of solid wastes in concrete structures at the generator's site. Shallow-land burial, with or without concrete linings in the trenches, is practiced in some cases, and rock-cavity repositories for solid LLW/ILW are in operation (Czechoslovakia: limestone, and the German Democratic Republic: salt).

DENMARK

In 1976, the Minister of Energy presented an energy plan to Parliament which called for five nuclear power stations to be completed by 1995. Because of public opposition, however, the decision to introduce nuclear power has been postponed several times. In the meantime, the utility organizations ELSAM and ELKRAFT have continued to plan for nuclear power. They have investigated potential power station sites and have sponsored design, feasibility, and site characterization studies for a salt dome repository.

ELECTRIC POWER DATA

Electricity Production

1981: 19.8 TWh--87% solid fuels, 12.8% oil, 0.2% hydro.

ORGANIZATION

The Danish Atomic Energy Commission, located in Copenhagen, has overall responsibility for nuclear energy matters. R&D in the nuclear field is performed primarily by the Risø National Laboratory. The Ministry of the Environment is charged with evaluating the results of repository field studies and their safety analysis.

WASTE MANAGEMENT

Investigators at Risø have been studying radioactive waste treatment and disposal for a number of years. They performed, in fact, the first known tests of a joule-heated ceramic melter for vitrifying simulated HLW. They have since been interested in the treatment of LLW, TRU properties, and geologic disposal of HLW.

In 1977, ELKRAFT and ELSAM initiated an extensive study of Denmark's waste disposal potential. After characterizing several salt domes in Northern Jutland, two sites were drilled to a depth of 3,500 m below sea level. The results of these and other studies led to the conclusion that HLW from Danish nuclear power plants can be safely disposed of in one of several suitable salt domes. Danish waste disposal strategy assumes HLW will be stored in aboveground facilities until it has been 40 years out of the reactor; hence it is anticipated that repository-disposal will not occur before the year 2040.(28)

Research on a LLW repository has been conducted in connection with the HLW program. The current concept uses a shaft/mine, also located in a salt dome.

In a project partly financed by the CEC, investigators at Risø are studying the migration of radionuclides through soils. Emphasis has been placed on the effect of various complexing agents upon migration.

EGYPT

Egypt's nuclear power program calls for total installed capacity of 8 GWe by the year 2000, with the first two PWRs scheduled to be operating in 1991-2. A once-through fuel cycle is anticipated, with storage of spent fuel at the reactor site until provisions can be made for final disposal.

An experimental radioactive waste management station has been installed at the site of Egypt's Nuclear Research Center, at Inchas (near Cairo). It includes a decontamination plant for low- and intermediate-level liquid waste, a cementation plant, and a shallow land disposal facility.(29)

FINLAND

Finland has four nuclear power plants: two PWRs supplied by the USSR, and two BWRs supplied by ASEA-Atom in Sweden; installation of a fifth unit is being considered.

The country has no commercial fuel cycle capability, but is laying the groundwork for construction of a geologic repository for spent fuel.

ELECTRIC POWER DATA

Electricity Production

1982: 39.5 TWh--35% nuclear, 32% hydro, 20% solid fuels, 10% oil/gas.

Nuclear Power

First operating power plant: 445 MWe PWR (1977)
Projection: 1984--2.2 GWe; 2000--3.2 GWe.

ORGANIZATION

The Finnish government oversees nuclear affairs through the Atomic Energy Commission, which is a component of the Energy Department in the Ministry of Trade and Industry. The nuclear power stations are operated by two state-owned power companies, IVO (Imatran Voima Oy) and TVO (Teollisuuden Voima Oy). These companies have established the Nuclear Waste Commission of Finnish Power Companies (YJT) to coordinate studies related to the management of their nuclear waste.

Waste management R&D is carried out mainly by the Technical Research Center (VTT), the Geological Survey of Finland, and the Institute of Radiation Protection (all in or near Helsinki).

NUCLEAR FUEL CYCLE

Spent Fuel Storage

Finnish fuel cycle and waste management policy depends on the reactor supplier. Spent fuel from USSR-built PWRs (440 MWe each) is to be returned to Russia for handling and disposal. Prior to transport to the USSR, the spent fuel is stored for five years at the Loviisa Nuclear Power Station.

Spent fuel from Swedish PWRs (660 MWe each) may be sent to another country for reprocessing or placed in terminal storage by Finland.

The Olkiluoto Power Station has pool storage capacity for its spent fuel until the year 2000. This storage capacity is to be supplemented with a new pool-type facility, handling all spent fuel arising at the station.

WASTE MANAGEMENT(15,30)

The Loviisa Power Station has tank storage facilities for wet reactor waste and plans to eventually build a cementation facility. Wet reactor waste from Olkiluoto is solidified in bitumen; dry waste is packaged in 200-ℓ drums, and both types are stored in a warehouse-type surface storage facility. Reactor waste will ultimately (1992) be disposed of in facilities constructed at the reactor sites, in bedrock at a depth of 50-120 m.

Reactor operating licenses give preference to the export of high-level waste (or spent fuel) to a foreign destination, but allow for final disposal in domestic territory and require that preparations be made for such disposal. In accord with the latter stipulation, work has been underway since 1977 to develop a geologic repository in one of Finland's granite formations. An inventory is being made of possible sites and supporting technical studies are proceeding. The repository schedule calls for site selection by the year 2000 and for start of disposal operations by 2020.

FRANCE

France has 22 PWRs, 7 GCRs, 1 LMFBR and 1 GCHWR in operation; 27 PWRs and 1 LMFBR are under construction or on order. France is considered a world leader in LMFBR technology, but earlier plans to proceed with FBR commercialization are being evaluated by the new government and may be deferred.

The country is very aggressive in developing domestic nuclear power and fuel cycle capability, marketing fuel cycle services, and exporting equipment, plants, and technology. Currently, emphasis is placed on expansion of fuel reprocessing capacity to satisfy domestic and foreign requirements, demonstration of the FBR fuel cycle, development of waste treatment and terminal waste storage technology, and construction of industrial waste treatment plants.

ELECTRIC POWER DATA

Electricity Production

1981: 276 TWh--38% nuclear, 26% hydro, 22% solid fuels, 14% gas/oil
1990: 70% nuclear.

Nuclear Power

First operating power plants: 40 MWe GCR (1959); 310 MWe PWR (1967);
273 MWe LMFBR (1973)
Projection: 1984--31.5 GWe; 1990--51.0 GWe; 2000--61.2 GWe.

ORGANIZATION

Government-owned Electricité de France (EdF) is the major producer and sole distributor of electricity in France and retains title to used nuclear fuel and all by-products. The French Atomic Energy Commission (CEA) controls all nuclear R&D, while its semi-autonomous subsidiary, COGEMA, handles all industrial fuel cycle activities, including reprocessing and conditioning of fuel cycle waste. Long-term management and disposal of radioactive waste is handled by another CEA subsidiary, ANDRA. The Institute for Nuclear Protection and Safety (IPEN) deals with safety problems, including waste disposal safety assessments, and prepares safety analyses and regulations. SGN, a COGEMA subsidiary, designs and builds fuel cycle plants for France and for other nations. The Minister of Industry has the licensing responsibility.

Fuel cycle and waste treatment research is conducted at a number of institutions, principally the Marcoule, Cadarache and Fontenay-aux-Roses Nuclear Research Centers of the CEA.

NUCLEAR FUEL CYCLE

Fuel Production

Reasonably assured uranium resources in France are estimated at 67,500 tU and short-term production capability at 3,500 tU/yr.

Two major gaseous diffusion plants are located in France: the Pierrelatte facility and Eurodif, a multinational project that reached a capacity of 10,800 tSWU/yr in 1982. The CEA has also built a pilot plant to demonstrate a chemical exchange process which operates efficiently only for low enrichments.

Oxide fuels for French and foreign PWRs are produced in plants at Romans and Dessel, Belgium; while plutonium-containing (MOX) fuels are fabricated in a plant at Cadarache. MOX fuel production capacity is 15 t/yr for LWR fuels and 5 t/yr for FBR fuels.

Spent Fuel Reprocessing

The first large reprocessing facility, UP1 at Marcoule, is still in operation, having reprocessed some 12,000 t of spent fuel over 25 years. Originally designed for the production of plutonium from magnesium-zirconium clad, natural uranium GCR fuel for the French military program, the plant was later adapted to reprocess EdF power reactor fuel, also natural uranium but with higher burnup.

The UP2 plant at La Hague, built to reprocess French civilian gas-cooled reactor (GCR) fuel, had treated over 4000 t of such materials by the end of 1981. In 1976, a new chop-leach headend plant was added to the facility to prepare oxide fuel for treatment in the UP2 solvent extraction system. Since that time, UP2 has been operated in a campaign mode, handling GCR fuel part of each year and reprocessing various types of BWR and PWR fuel the rest of the year. Annual LWR fuel throughput has increased steadily, reaching 221 tHM during an eight-month campaign in 1983.

Current plans for the future call for: installation of a new headend, MAR-400, at Marcoule and transfer of all gas-graphite reactor fuel reprocessing to Marcoule by 1985, and expansion of La Hague capacity to 1600 t/yr by the early 1990s. This involves construction of UP3, to be dedicated to foreign fuel for a 10-year period, and expansion of UP2 to 800 t/yr.

France also has an advanced FBR fuel reprocessing technology development program.

WASTE MANAGEMENT

National plans for waste management(31) are: vitrify all HLW, provide interim storage for the waste glass canisters in an engineered surface facility, then isolate in a suitable geologic formation (granite, salt, clay or seabed). Liquid LLW is processed by conventional techniques, producing a decontaminated stream which can be discharged into the environment. Solid LLW/ILW is conditioned and placed in engineered concrete structures at or near the surface. If feasible, processes for isolating alpha-emitters are to be developed and used.

Waste Treatment

Since June 1978, COGEMA has successfully operated the AVM, a demonstration plant for vitrification of high-level waste, treating HLW from the reprocessing plant at Marcoule. Using a two-stage process (rotating-tube calciner and induction-heated metal melter), AVM produces borosilicate glass at 15 kg/hr, or one waste canister (360 kg glass) per day. Waste canisters are stored in an onsite underground vault. COGEMA has started construction of AVH, the first vitrification plant at La Hague, a multi-line facility with a maximum-rated capacity of about 40 kg/hr per line. An AVM-type plant is being installed at Sellafield in Great Britain and similar facilities are being designed for the Eurochemic site in Belgium. Current research emphasis is on the development of a higher-temperature melter (1,400°C) heated by induction.(32,33)

With a national commitment to plutonium-fueled fast breeder reactors and to reprocessing and recycling of spent LWR fuel, the French regard TRU waste as one of their most important waste management problems. Accordingly, they are devoting much effort to minimizing waste generation, reducing waste volumes, recovering plutonium from waste and developing suitable waste forms and disposal methods.

Low- and intermediate-level radioactive waste is reduced in volume by mechanical compaction or by incineration, incorporated into a cement, resin, or bitumen matrix, loaded into drums or concrete casks, and transported for disposal to the La Manche Center, where ANDRA operates a surface disposal facility for LLW/ILW. Two types of structure are in use: below-grade concrete "monoliths," in which the waste packages (metal drums and boxes or cement casks) are embedded in concrete; and tumuli, situated above the monoliths, in which the stacked waste packages are covered with earth that is then planted with indigenous grasses and shrubs. The site has the capacity for about 400,000 m^3 of waste, and is slightly more than half filled.

Arisings of LLW/ILW now amount to 20,000 m^3/yr; by the year 2000, the inventory will amount to about 900,000 m^3, with an annual rate of increase of about 70,000 m^3. With this large a disposal load, ANDRA is searching for a second disposal site, preferably in Southeastern France, close to the concentration of reactor and fuel cycle plants. ANDRA's present schedule requires the next LLW/ILW disposal site to be ready for service by 1990.

France intends to place HLW glass canisters and TRU waste packages in deep geologic repositories. The country has granite, salt and clay formations offering potential repository sites and is interested in the subseabed disposal option.

Until 1981, the French repository development program emphasized the characterization of crytalline rock media.(34) Under the new government, the program scope was expanded to include salt and clay media. Current objectives are: selection of a repository site by 1987; an underground research laboratory in operation by 1988; startup of a TRU waste repository by 1992 and trial emplacement of HLW canisters in a repository in the same year. Meanwhile research continues in a number of areas: migration of radionuclides through beds of various minerals and clays; geohydrologic studies; thermal effects in rock formations; and sealing of fissures.

GERMANY (FEDERAL REPUBLIC)

The Federal Republic of Germany (FRG) has seven PWRs and five BWRs in operation, 12 PWRs and 2 BWRs under construction or on order. Two demonstration reactors, one HTGR and one LMFBR are also under construction. In the past, the federal government has been a strong advocate for the growth of nuclear power, promoting the construction of LWRs and working to develop advanced reactor technology as well as completely domestic fuel cycle capability. Industry has been a major exporter of nuclear plants, fuel cycle services, and nuclear technology. In recent years, however, political opposition in West Germany has led to the government giving priority to conservation and indigenous coal development, utilizing nuclear power only as necessary to fulfill the incremental electrical capacity needs.

ELECTRIC POWER DATA

Electricity Production

1981: 368.8 TWh--62% solid fuels, 18% oil/gas, 14.5% nuclear, 5.5% hydro
1982: 18% nuclear.

Nuclear Power

First operating power plants: 52 MWe PHWR (1962); 640 MWe BWR (1972);
328 MWe PWR (1969); 296 MWe HTR (1985);
295 MWe LMFBR (1987)

Projection: 1984--12.3 GWe; 1990-22.9 GWe; 2000--29.3 GWe.

ORGANIZATION

The federal government coordinates the nuclear program and sponsors fuel cycle and waste management R&D. It is charged by law to design, build, and operate any radioactive waste disposal facilities. The privately owned utilities are responsible for the fuel cycle, including spent fuel storage, reprocessing and treatment of associated waste; they established the German Fuel Reprocessing Company, DWK, to handle their fuel cycle activities. The nuclear utilities pay the cost of waste disposal by the government.

Development of fuel cycle and waste management technology is coordinated and funded by the Ministry for Science and Technology (BMFT); design, licensing and operation of final waste disposal sites is assigned by law to the Federal Physical-Technical Institute (PTB). Development of repository technology is managed by IfT, the Underground Storage Institute of GSF. Waste management R&D support and engineering services are provided by several research institutes and private companies, notably the Karlsruhe (KfK) and Jülich (KFA) Nuclear Research Centers, the Hahn-Meitner Institute (HMI), the Federal Institute for Geosciences and Natural Resources (BGR), ALKEM GmbH and NUKEM GmbH.

NUCLEAR FUEL CYCLE

Germany has an extensive commercial fuel cycle program, based for many years on the concept of recycling plutonium to breeder reactors, and possibly to LWRs. It includes worldwide uranium exploration, participation in international uranium enrichment projects, extensive UO_2 and mixed-oxide fuel fabrication capability, and development of commercial fuel reprocessing and waste management facilities.

Several years ago, adequate provision for nuclear waste management became a precondition for issuing construction permits for additional reactors. In response to this requirement, DWK started planning for a complete spent fuel recycle and waste management center, the Nukleares Entsorgungs-Zentrum (NEZ). The NEZ provided for interim spent fuel storage (3,000 t), reprocessing

(1,400 t/yr), uranium and plutonium conversion and storage, MOX fuel fabrication, conditioning of radioactive waste, and disposal of solidified waste in a salt repository--all at the same site. A 12-km^2 area near the town of Gorleben, Lower Saxony, was purchased and site characterization and facility design activities began. In 1979, the government of Lower Saxony decided that construction of the large reprocessing plant at Gorleben was technically, but not politically, feasible and recommended that reprocessing be done elsewhere in smaller plants.

Current FRG strategy includes: thorough evaluation of the final storage of spent LWR fuels as an alternative to reprocessing; temporary dry storage of spent fuels at AFRs; interim reprocessing of FRG fuels by COGEMA at La Hague; construction of one or more small reprocessing plants; construction of a salt dome repository at Gorleben for HLW, TRU waste and possibly spent fuel; and conversion of the abandoned Konrad iron mine into a repository for non-TRU waste.

Fuel Production

Germany has limited indigenous uranium resources and an installed mining/milling capacity of 40 t/yr. The German company, Uranit GmbH--a partner with British and Dutch companies in the URENCO consortium--is building a 400-tSWU/yr gas centrifuge enrichment plant at Gronau. Construction is expected to be complete in 1985.

Fuel elements are produced by several companies in Germany, for test irradiation purposes, for domestic commercial use and for export. Plutonium-bearing (MOX) fuel is fabricated by ALKEM GmbH (capacity: 40 t/yr for LWR fuels, 10 t/yr for FBR fuels); pebble-type elements for HTGRs by HOBEG GmbH; and specialty fuel for research and materials test reactors by NUKEM GmbH.

Spent Fuel Management

Two companies, GNS and Transnuklear, have developed relatively low-cost cast-iron casks usable for both transport and dry-storage of spent fuel. DWK plans to use this type of cask for temporary fuel storage at two 3,000-t AFR spent fuel storage facilities. Construction of the first AFR, located at Gorleben, was completed in 1983; the second AFR is to be built at Ahaus, in Western Germany.

Germany has had a fuel reprocessing pilot plant, WAK, in hot operation since 1971 at the Karlsruhe Nuclear Research Center. The facility has been used for routine processing of spent fuel and as a test facility for new processes and components developed at KfK's Institute for Hot Chemistry. WAK has a chop-leach headend, hence can handle LWR and FBR fuel. It uses a Purex solvent extraction system with mixer-settlers and is designed for contact maintenance.

When the DWK proposal to build a 1400-tU/yr reprocessing plant at Gorleben was rejected by the Lower Saxony government, the company began to plan for one or more 2 t/day facilities. Overall plant design is based on a "cavern" concept, in which plant modules are mounted in such a way that they can be removed remotely for maintenance, without the need to decontaminate processing cells. Formal licensing procedures have commenced for two potential sites, one in Bavaria and one in Lower Saxony, and commissioning of the first plant is scheduled for 1992.

Development of advanced processes for LWR and FBR fuel is carried out at Karlsruhe, while thorium fuel reprocessing technology is the responsibility of KFA's Institute of Chemical Technology at Jülich.

WASTE MANAGEMENT

Waste Treatment(35-37)

In a joint project, BMFT and DWK are building a waste vitrification pilot plant, PAMELA, on the Eurochemic site at Mol, Belgium. It is to demonstrate the liquid-fed ceramic melter immobilization process, using existing Eurochemic HLW, and will probably be the forerunner of vitrification facilities to be installed at FRG's reprocessing plants. Startup is scheduled in 1985.

In a separate effort, the FIPS process for thorex waste has been developed at the Jülich Research Center. In this process, the waste solution is converted to a slurry, dried on a drum dryer and melted to form a glass.

Small amounts of alpha-contaminated radioactive waste are produced at ALKEM's mixed-oxide fuel fabrication facility near Hanau, at the WAK reprocessing plant near Karlsruhe, and at various nuclear research centers. Since it is now national policy to place all radioactive waste in deep geologic repositories, and since it will be years before a repository will be ready for use, TRU waste is being conditioned and stored in high-strength surface facilities at Hanau and Karlsruhe. Alpha-contaminated waste is fixed in concrete. A bituminization plant began operation at Karlsruhe in 1972 but was shut down in 1977 because of concerns over the safety of bitumen in storage. In other R&D, the Karlsruhe Center developed an acid digestion process for combustible TRU waste and designed the ALONA facility. ALONA has been installed in Eurochemic space at Mol, Belgium, and is being used to treat Eurochemic waste.

Low- and intermediate-level waste in Germany is immobilized and placed in interim storage in large surface facilities at Hanau, Karlsruhe, Gorleben and other nuclear waste collection centers. Neither land burial nor sea dumping is practiced, and ultimate disposal is awaiting the completion of geologic waste disposal facilities at the Konrad mine near Braunschweig.

Several LLW/ILW conditioning techniques are in use: volume reduction of liquid waste by evaporation, and of solid waste by incineration or mechanical compaction; bituminization of liquid waste in a screw extruder-evaporator which allows simultaneous removal of water and mixing of the residual salts with bitumen; cementation of evaporator concentrates and ion exchange resins; and incorporation of solids in an organoplastic resin matrix. Recent work has been directed to developing a process for producing cement/waste pellets which would then be mixed with fresh cement and slurried into a salt mine cavern. The concept is to be tested at Asse.

Waste Disposal(28,38)

PTB has the mandate to construct and operate the following facilities: engineered 100-yr storage for cylinders of krypton; engineered interim storage (20-30 yr) for vitrified HLW; one or more mines for final disposal of all conditioned low-, intermediate-, and high-level waste; and a facility for the injection of tritium-containing water in suitable, deep porous geological strata. The Institute is proceeding to license and build a waste storage and disposal complex at Gorleben and to seek approval to build rooms for disposal of low-level, non-alpha waste in the abandoned Konrad iron mine. Licensing of the Asse II mine for disposal of LLW and for R&D on ILW disposal is also being considered.

The Gorleben repository site is situated on a salt dome which is 15 km long, 5 km wide and 3,000 m deep. Operating plans call for receipt of 33,000 LLW and ILW drums and 2,300 HLW glass canisters per year. The HLW canisters are to be stacked in 300-m deep boreholes, drilled in the floor of a repository drift. Preliminary site characterization has been completed, and preparations are being made to sink two exploratory shafts. The repository is scheduled to be commissioned in 1995.

The former Asse salt mine, also located near Braunschweig in Lower Saxony, has been used as an experimental facility since 1965. Between 1967 and 1978, about 124,000 LLW and 1,300 ILW drums were, on a test basis, disposed of in the mine. Since the end of 1978, when the LLW operating license expired, the facility has been used for a variety of in situ tests.

In 1980, BMFT announced a four-year program to evaluate the technology for geologic disposal of spent fuel as an alternative to spent fuel reprocessing. The program calls for development of various conditioning and packaging concepts, studies of repository design, a search for suitable repository sites, and supporting experimental work.

INDIA

India has two BWRs and three PHWRs installed, and five more PHWRs partially built. The nuclear power program is to proceed to FBRs fueled with plutonium and eventually to self-sustaining thorium-uranium-cycle reactors. Development of complete indigneous fuel cycle capability, including reprocessing, is a major program objective.

ELECTRIC POWER DATA

Electricity Production

1982: 120 TWh--1.7% nuclear.

Nuclear Power

First operating power plants: 200 MWe BWR (1969); 202 MWe PHWR (1973)
Projection: 1984--1.0 GWe; 1990--1.9 GWe; 2000--4.4 GWe.

ORGANIZATION

Essentially all activities concerned with the back end of the fuel cycle are conducted by the various divisions of the Department of Atomic Energy. Major components include the Bhabha Atomic Research Center at Trombay, nuclear energy research and development; the Reactor Research Center at Kalpakkam, FBR research and development; the Nuclear Fuels Complex at Hyderabad, nuclear fuel production; and the fuel reprocessing organizations at the Tarapur and Kalpakkam power stations.

In late 1983, the Atomic Energy Regulation Board (AERB), an independent organization, was established by the government to establish safety standards and regulations for enforcing the nation's nuclear regulatory and safety requirements.

NUCLEAR FUEL CYCLE

National objectives continue to emphasize development of complete fuel cycle self-sufficiency, with domestic capability for uranium milling and conversion to UO_2, fuel fabrication, reprocessing, and waste treatment and disposal. If the enriched UF_6 supply for the BWRs is eliminated, because of India's refusal to sign the Non-proliferation Treaty, they may be fueled with UO_2-PuO_2.

Fuel Production

India's reasonably assured uranium reserves are estimated at about 32,000 tU, while thorium deposits in the monazite sands at Kenalas and Onissa are estimated at 363,000 tTh. Uranium mining and milling capacity is currently 200 tU/yr.

The Nuclear Fuel Complex at Hyderabad fabricates Zircaloy structural materials and a variety of fuel: natural UO_2 assemblies for India's PHWRs; enriched UO_2 assemblies for the BWRs; and ThO_2 pellets for the new Fast Breeder Test Reactor at Kalpakkam.

Spent Fuel Management

India is developing a closed fuel cycle, with domestic reprocessing. The country lacks a modern interstate road system and the railroads are multigage, requiring frequent transloading of cargo. Consequently, the AEC is attempting to minimize the need for transport of highly radioactive materials, and the country's reprocessing requirements are to be met with a small (100 tHM/yr) reprocessing plant located near each major nuclear power center. Hence, there is little need for major facilities for either extended storage or transport of nuclear fuels. The nuclear industry depends on AR pools to handle interim storage requirements.

Reprocessing

Reprocessing of spent fuel was started in 1964 at Trombay, in a 0.1-0.15-t/day pilot plant, intended primarily to reprocess the fuel from a test reactor. The plant was shut down in 1974, decontaminated, and renovated to allow its continued use in reprocessing test reactor fuel.

The Trombay project was followed by construction of the reprocessing plant at Tarapur to handle HWR and BWR fuels. The plant is equipped with a chop-leach headend and, except for the headend cell with provisions for remote maintenance, uses remote decontamination, followed by direct maintenance. This facility, idle since being completed in 1976, began reprocessing fuel in December 1982 from the Rajasthan nuclear power station. A second 100-t/yr plant is to be built at Kalpakkam, to process HWR and FBR fuels.

WASTE MANAGEMENT

Waste Treatment

HLW solidification R&D has focused on the vitrification facility of the Waste Immobilization Plant (WIP) at Tarapur. Based on a semi-continuous pot process developed at BARC, the WIP produces a borosilicate glass with up to 30% waste loadings. Canisters are stored in a vault partially under ground. In April 1983, the various plant service systems of the Tarapur facility had been commissioned; design verification tests of the various process equipment systems and assemblies were complete, and the plant was scheduled for radioactive operation later that year. A similar plant is now being set up at Trombay.(39)

Various conditioning techniques are in use for transuranic and low-level waste: incineration, compaction, chemical decontamination, and encapsulation in cement, bitumen or polymer matrices. Waste packages are disposed of in unlined earth excavations, reinforced concrete trenches and steel-lined concrete tile-holes.(40)

Waste Disposal

India intends to develop a repository for high-level and TRU wastes. A geologic survey for potential repository sites has been conducted, and current effort is focused on the investigation of candidate sites in peninsular gneisses and granite formations. An experimental research station is being set up in an unused section of an underground mine at Kolar, near Bangalore, to examine the behavior of the host rock under simulated repository conditions. Program plans also include the construction of an engineering-scale pilot repository in the late 1990s to develop and test transport and disposal techniques and methods.(41)

ISRAEL

Interest in nuclear power began early and an Atomic Energy Commission was established in 1952. A 26 MWe natural uranium research reactor was built at

Dimona in the early sixties; a 5 MWe research reactor was built at Nahal Soreg, south of Tel Aviv, and the Israeli government is reportedly planning to build a 900 MWe LWR.

A reprocessing plant, capable of separating weapons grade plutonium from spent fuel, is reportedly in operation at Dimona.

ITALY

Italy has one GCR, one PWR and one BWR in operation, and two BWRs and one LWCHWR under construction. The government is also supporting advanced reactor development, with part ownership of Super Phenix, with construction of a 40 MWe HWR and a 150 MWt experimental FBR. The government and public are generally supportive of nuclear power, but plant siting proposals have run into extensive opposition from local communities involved. This problem may be eased as the result of a recent decision to pay communities for their acceptance of nuclear facilities.

ELECTRIC POWER DATA

Electricity Production

1981: 181.7 TWh--59% oil/gas, 26.6% hydro, 12.4% solid fuels, 2% nuclear
1982: 3.7% nuclear.

Nuclear Power

First operating power plants: 150 MWe GCR (1964); 250 MWe PWR (1965);
875 MWe BWR (1981); 40 MWe LWCHWR (1986)

Projection: 1984--1.3 GWe; 1991--2.2 GWe; 2000--6.7 GWe.

ORGANIZATION

The Ministry of Industry has overall responsibility for nuclear energy matters with decisions subject to approval by Parliament. Italian organizations with major fuel cycle R&D roles include the National Commission for Research and Development of Nuclear Energy and Alternative Forms of Energy (ENEA); AGIP Minerale (an ENI subsidiary), nuclear fuel cycle; and NUCLECO, a company formed to treat and dispose of low- and intermediate-level wastes. ENEA has safety and regulatory responsibilities and promotes development of the nuclear industry.

The Casaccia Center, located in Rome, has a varied nuclear R&D program. The Trisaia Center, at Rotondella in Southern Italy, is the site of the ITREC Fuel Reprocessing Pilot Plant and of clay repository studies. The Saluggia Center, near Torino in Northern Italy, is the site of the EUREX Fuel Reprocessing Pilot Plant, the construction of which was partly funded by Euratom.

NUCLEAR FUEL CYCLE

Fuel cycle strategy assumes: spent fuel will be reprocessed to provide plutonium for breeder reactors; HLW will be vitrified and held in engineered storage for 50-60 years; and HLW and other long-lived waste will be placed in a geologic repository, probably built in a clay formation.

Fuel Production

Italy has reasonably assured uranium ore resources equivalent to 2,900 t of uranium and plans startup of mining and milling operations at a rate of 240 tU/yr in the early 1990s.

The country owns a 25% interest in the Eurodif enrichment venture in France, has UO_2 fuel fabrication capability, and plans to build a 9 tHM/yr plant at Rotondella to fabricate fast breeder PuO_2/UO_2 fuels for the Super Phenix FBR core.

Spent Fuel Management

Current spent fuel storage requirements are being met with pool storage, but authorities believe a large AFR storage facility will be needed by 1995 and are considering installation of a 1000-tU-capacity pool, probably at the site of a planned commercial reprocessing plant. As an alternative to the pool facility, dry storage is also being evaluated.

Italy has two pilot-scale reprocessing plants, EUREX and ITREC, and the construction of an industrial-scale plant (1200 tHM/yr) has been evaluated. In the interim, limited quantities of Magnox fuel are being treated by BNFL at Sellafield (UK).

The EUREX pilot plant, built between 1965 and 1968 and located at the Saluggia Center, initially operated between 1970 and 1974. It was first designed to reprocess highly enriched MTR fuel and later modified to treat 50 to 100 kg/day of natural and low-enrichment uranium fuel. The pilot plant has since been equipped with a new headend cell with a shear to reprocess power reactor fuel, and reprocessing experiments have begun on CANDU-type fuel elements from Canada.

The ITREC pilot plant at the Trisaia Center was completed in 1968 and started active operation about 1975. It has a chop-leach headend and was designed to reprocess 15 kg/day of thorium-uranium fuel from the Elk River reactor under a joint program with the U.S. The plant's current assignment is to process fuel from Italy's 120-MWt fast fuel test reactor (PEC).

WASTE MANAGEMENT

Waste Management

For immobilization of high-level waste, Italy initially selected a pot vitrification process (Ester) based on the rising-level concept.(42) Intending to use the process for HLW from the Eurex reprocessing plant, a hot-cell Ester facility was built at Euratom's Ispra laboratory, and a nonradioactive pilot plant (IVET) at the Trisaia Center. However, a recent change in Italian policy concerning the management of Eurex waste has increased the required capacity of the new vitrification plant, and ENEA is now considering the installation of a commercially available continuous process. Meanwhile Ester process testing continues at Ispra and Trisaia to determine actual process capacity with the present plant configurations and to assess the performance of the ancillary facilities.(43)

Low-level and plutonium-contaminated waste is conditioned in various ways and stored in drums, principally at the research centers and power plant sites.

Waste Disposal

Research on geologic waste disposal is conducted by ENEA, in part within the framework of a cost-sharing contract with the CEC. Although Italy has salt and crystalline rock formations, the major thrust is on clay, which is found throughout Italy. Work to date includes preparation of an inventory of potential repository sites; in situ heating experiments and a deep-drilling operation at Trisaia; and a variety of supporting R&D at Casaccia and various university institutes.

During the next few years, research will be focused on studies of: pliocene clay basins; heat dissipation, corrosion and plastic deformation properties of clay; the role of clays as geochemical barriers for radionuclide migrations; response to seismic disturbances; and the geothermal behavior of conceptual waste repository design. ENEA is also building an underground laboratory, which will be used for in situ tests.(15)

JAPAN

Japan has 14 BWRs, 12 PWRs, one GCR and the Fugen HWR operational, while 6 BWRs, 6 PWRs and one LMFBR are under construction or on order. The government's strategy is to install LWRs for near-term power production; develop an advanced thermal heavy-water reactor; aim for commercial operation of fast breeder reactors by the year 2010; and eventually depend heavily on fusion power. The government also considers it essential to build an independent commercial nuclear fuel cycle capability, including export of nuclear equipment and technology. Fuel cycle strategy calls for maximum utilization of plutonium resources, with Pu recycle to FBRs, ATRs and LWRs.

ELECTRIC POWER DATA

Electricity Production

1981: 583.2 TWh--52% oil/gas; 15.7% hydro; 15.1% nuclear;
16.2% other sources.

Nuclear Power

First operating power plants: 159 MWe GCR (1966); 340 MWe BWR (1970);
320 MWe PWR (1970); 148 MWe HWR (1979);
280 MWe FBR (1991)

Projection: 1984--19.0 GWe; 1990--31.3 GWe; 2000--49.8 GWe.

ORGANIZATION

The government funds most of the nuclear R&D, including fuel cycle and waste management programs, and is responsible for disposal of HLW. Industry is responsible for the commercial fuel cycle, for developing technology (with government help) and industrial capability for disposal of LLW, and is to pay for HLW disposal on the basis of the principle that "the polluter pays."

Several government agencies and private companies have major fuel cycle and waste management responsibilities.

The Science and Technology Agency (STA), established to promote and administer research and development for the government, operates in the nuclear field primarily through the Power Reactor and Nuclear Fuel Development Corporation (PNC) and the Japan Atomic Energy Research Institute (JAERI). PNC develops and demonstrates advanced reactors and fuel cycle technology. JAERI's program is focused primarily on the Institute's responsibility for safety assessment in all aspects of the nuclear field. Both PNC and JAERI operate facilities at Tokai-mura and O-arai.

The Ministry of International Trade and Industry (MITI) maintains governmental oversight of commercial nuclear power and nuclear fuel cycle activities.

The Radioactive Waste Management Center (RMC), sponsored by a number of utilities and manufacturers, is responsible for LLW disposal. Japan Nuclear Fuel Services Co. (JNFS) was organized by a large group of utilities and manufacturers to build and operate commercial reprocessing facilities.

NUCLEAR FUEL CYCLE

With only very limited indigenous uranium resources and a national commitment to become self-sufficient with regard to their nuclear fuel supply, the Japanese rely on fuel reprocessing and plutonium recycle. In keeping with these objectives, Japan is developing domestic industrial capability for uranium enrichment, reprocessing and waste treatment. Since a commercial-scale reprocessing plant will not be in operation before 1990, the utilities have contracted to have over 4,600 tU of their fuel treated by BNFL (UK) and COGEMA (France).

Fuel Production

Domestic uranium resources are estimated at only 7,700 tU, while mining and milling capacity now runs at 7 tU/yr. PNC has installed a 200 tUF_6/yr plant at the Ninyo Toge mine for conversion of U_3O_8 to UF_6.

PNC has been operating a centrifuge enrichment pilot plant at Ninyo Toge for several years, gradually building up to the current capacity of 75 tSWU/yr, and plans to follow with a 200 tSWU/yr demonstration plant at the same site. Full operation of the latter is scheduled for 1988. Construction of commercial enrichment facilities is being evaluated by the electric utilities.

Japan relies on private industry to fabricate uranium fuels and on PNC for development and fabrication of MOX fuels. PNC's Plutonium Fuel Fabrication Facility (PFFF) has two fabrication lines with capacities of 15 kg/day for the FBR fuel line and 10 t MOX/yr for the ATR line. A new MOX fuel fabrication plant, currently being built, will have a capacity of 40 t/yr, which can be expanded to 140 t/yr.

Spent Fuel Management

Because nuclear power and spent fuel reprocessing plants are sited along the coast, harbor facilities are easily accessible and spent fuel is transported to reprocessing facilities in Japan and abroad by ship directly from the reactor site. Current policy is to store spent fuel in water pools at the reactor site (with rod consolidation) until it can be moved to a foreign or domestic reprocessing plant and the nuclear utilities depend on AR pool storage. This policy is now being reassessed, and consideration is being given to constructing AFR storage facilities. A 3,000-tU AFR is planned for the first commercial reprocessing plant.

The Tokai-mura fuel reprocessing pilot plant (0.7 tHM/day), owned and operated by PNC, started radioactive operation with spent fuel in September 1977. The plant uses a chop-leach headend designed to be remotely maintained, with provision for remote decontamination of the cell and equipment in case direct contact is required for major repair or modification. All other plant areas are maintained by contact maintenance after the necessary decontamination. By December 1982, the plant had processed about 175 t of spent fuel. The Tokai-mura plant has also tested several co-processing flowsheets, designed to yield a mixed Pu-U stream of controlled composition, and PNC has developed a technique for direct denitration of the co-conversion product to yield fuel-grade MOX.

A commercial reprocessing plant for LWR fuel, designed for a 6 tHM/day throughput, will be built and operated by Japan Nuclear Fuel Service, Limited. Startup is planned for 1995.

PNC is managing an intensive R&D program supporting the design and construction of the FBR Fuel Reprocessing Test Facility, a 120-kg HM/day pilot plant. The facility is being built to demonstrate FBR fuel reprocessing technology and to handle spent fuel from the MONJU FBR. Hot operation is scheduled for 1995.

WASTE MANAGEMENT(44)

Waste management strategy calls for vitrification of HLW, volume reduction and immobilization of other waste, and surface storage of waste packages until provision can be made for disposal.

Waste Treatment(45)

Current HLW studies are aimed at a) having PNC's Vitrification Pilot Plant in place by 1990, ready to handle HLW from the Tokai Works fuel reprocessing plant, b) demonstration of a similar process for solidifying HLW from FBR fuels, and c) preparations to receive solidified HLW from French and British reprocessors.

During 1981, PNC completed construction on a major new R&D facility at the Tokai site, the Chemical Processing Facility (CPF). The building has two hot cell lines, one designed for studies on the application of the PUREX process to irradiated FBR fuel, and one equipped to vitrify HLW and to characterize the waste products. JAERI is concerned with evaluating HLW form behavior under transport, storage and disposal conditions, and started tests in the new Waste Safety Testing Facility (WASTEF) at Tokai. WASTEF has five hot cells equipped to vitrify radioactive waste, weld and store waste canisters, and take and characterize samples of glass logs.

PNC, JAERI and supporting contractors are studying a variety of techniques for treating and immobilizing plutonium-contaminated and other non-high-level waste: incineration or acid digestion of combustible solids; microwave or electroslag melting of residues, incinerator ash, etc.; compaction of cladding hulls; and fixation in bitumen or resins. Several of these techniques are to be applied in PNC's Plutonium Waste Treatment Facility at the Tokai Works, scheduled to be commissioned in 1987.

Installation of an offgas treatment facility for PNC's Tokai-mura fuel reprocessing plant was completed in early 1982. The plant includes cryogenic distillation components for the recovery and separation of xenon and krypton.

Japan may store its HLW canisters for as long as 100 years in engineered surface storage facilities before sending them to a repository, and PNC expects to commission a HLW vitrification/glass storage facility at Tokai in 1990 to handle the product from the Vitrification Pilot Plant. A storage pit-vault concept is used.

The waste repository program is assigned to two organizations: PNC is responsible for technology development and demonstration, JAERI for safety evaluation. The program objective is to have a geologic repository ready for operation by approximately 2020. Selection of a host rock is not expected to occur for several years.

Authorities have long planned to dispose of immobilized LLW in the Pacific Ocean and have carried out a comprehensive safety assessment of this disposal mode. Planned test drops of LLW drums have been deferred indefinitely, however, and a search is being made for suitable land-disposal sites in the event ocean dumping is banned by international action. Supporting studies, intended to evaluate the safety of land disposal, are also in progress.

KOREA

The Republic of Korea (ROK) has two PWRs and one PHWR installed, six PWRs under construction, and four more PWRs planned. Installation of one FBR in the late 1990s is also being considered.

Nuclear energy self-sufficiency is a national goal, and fuel cycle capability is being developed. Long-term planning assumes that either AFR spent fuel storage or domestic reprocessing will be required by the early 1990s. In the event the reprocessing option is selected, the plutonium will be recycled to an FBR or to thermal power stations.

ELECTRIC POWER DATA

Electricity Production

1983: 41.5 TWh--54.8% oil, 14.8% nuclear, 5.2% hydro
1991: 33.3% nuclear.

Nuclear Power

First operating power plants: 556 MWe PWR (1978); 629 MWe HWR (1983)
Projection: 1984--1.8 GWe; 1990--7.4 GWe; 2000--11.2 GWe.

ORGANIZATION

Nuclear policy, R&D and radiation safety are the responsibility of the Atomic Energy Bureau (AEB), a branch of the Atomic Energy Commission (AEC) under the Ministry of Science and Technology (MOST). Korea Advanced Energy Research Institute (KAERI) is responsible for developing nuclear fuel cycle technology, much of the work being done at KAERI's Daeduck Engineering Center. Commercial PWR fuel fabrication is handled by Korea Nuclear Fuel Company (KNFC).

NUCLEAR FUEL CYCLE(46)

Korea has indigenous thorium and low-grade uranium ores and is building a 3-t/day U_3O_8 pilot plant for uranium extraction. A 100-tU/yr uranium conversion plant ($UF_6 \rightarrow UO_2$) was completed in 1982, a 10-tU/yr fuel fabrication pilot plant has been operating since 1978, and plans are being made to build a 200-t/yr PWR fuel production plant.

Spent Fuel Management

Energy planners expect storage capacity for spent fuel to become inadequate during the period 1992-1997, and a major study has been started to evaluate the alternatives. Options under consideration include permanent storage of spent fuel, reprocessing with recycle to thermal reactors, and recycle of plutonium to FBRs.

Waste Management

Liquid waste is treated by various techniques and solidified in cement (reactor waste) or bitumen (KAERI). Shallow land disposal operations are to begin in 1987 under the responsibility of the non-profit Korea Radwaste Disposal Agency.

MEXICO

At one time, the government of Mexico was working toward a national goal of 20 GWe installed nuclear capacity by the year 2000, and several fuel cycle R&D facilities were reported to be under construction at the Salazar Nuclear Center near Mexico City. One of these facilities was thought to be a pilot-scale reprocessing plant. Currently, the country has two 650 MWe BWRs under construction at Laguna Verde, scheduled for completion in 1986 and 1989, and nuclear power goals are being reevaluated. The national regulatory body has recommended that plans be started at once for an AFR storage facility and a repository for spent fuel.

NETHERLANDS

The Netherlands has two LWRs and implementation of plans to build other nuclear plants is awaiting resolution of the country's waste management problems and a parliamentary decision. The government favors expansion of nuclear power capacity, but faces public opposition; the utilities want three more plants (1,000 MWe each). Polls in a lengthy series of lightly attended public meetings have shown a large number of those attending as being opposed to nuclear power.

ELECTRIC POWER DATA

Electricity Production

1981: 64.1 TWh--75.5% oil/gas, 18.5% solid fuels, 6% nuclear.

Nuclear Power

First operating power plants: 50 MWe BWR (1969); 445 MWe PWR (1973)
Projection: 1984--0.5 GWe; 2D00--0.5 GWe.

ORGANIZATION

Overall control of nuclear matters is exercised by the Ministries of Economic Affairs, Public Health and Environmental Control, and Social Affairs; Parliament approves decisions of the ministries. Organizations with major waste management roles include the Netherlands Energy Research Foundation (ECN) at Petten, the Geological Survey and a private company, COVRA (Central Organization for Radioactive Waste). COVRA was founded in 1982 to collect, treat and store radioactive waste.

NUCLEAR FUEL CYCLE

Holland has no indigenous uranium resources, but is a full partner with France and the United Kingdom in the Urenco uranium enrichment consortium and has a 200-tSWU enrichment plant operating at Almelo. Reactor fuel is bought from foreign suppliers.

The country participated in the Eurochemic fuel reprocessing project and has contracted to have spent fuel reprocessed in France and England.

WASTE MANAGEMENT

Reactor and institutional waste is treated in various ways and conditioned by incorporation in concrete or resins. From 1965-1982, low- and intermediate-level waste was disposed at sea under the surveillance of the OECD/Nuclear Energy Agency. Waste is currently being stored, pending definition of national waste disposal policy.

In 1979, the government submitted a report to Parliament indicating that radioactive waste can be stored safely in underground salt domes in state-owned property in the northeastern region of the country. Plans were made to drill exploratory holes, but these plans have been indefinitely deferred. Consideration has also been given to constructing a repository in a salt diapir below the seabed. With CEC financial support, the Dutch are working in several areas of geologic waste disposal technology: in situ tests in the Asse Salt mine in the FRG; theoretical studies of thermal effects in salt dome repositories; measurement of distribution coefficients of various radionuclides in soil samples; hydrogeologic evaluations; and safety assessment.(28)

PAKISTAN

Pakistan has one CANDU-type HWR in service, commissioned in 1972, and authorities hope to have a PWR operational by 1990. Government fuel cycle policy calls for development of domestic capability for uranium production and enrichment, fuel fabrication and reprocessing.

NUCLEAR FUEL CYCLE

The Pakistan Institute of Science and Technology in Rawalpindi has a small laboratory-scale reprocessing facility, and Pakistan reportedly plans to set up a nuclear complex, including reprocessing capability, at the Chashma site on the Indus River. A fuel fabrication plant started operations there in 1980, and construction is reportedly proceeding on a 300 kg U/day reprocessing plant.

Liquid waste is discharged into seepage pits or diluted and pumped into the ocean. Solid wastes are subject to shallow-land burial or are disposed of in concrete-lined trenches.

SOUTH AFRICA

South Africa has two PWRs, one commissioned in 1984 and the other scheduled for startup in 1985. No commitment has been made for additional nuclear power stations.

Overall control of the nuclear program and licensing and regulatory affairs are handled by the Atomic Energy Corporation of South Africa, Limited (AEC). The Nuclear Development Corporation of South Africa Ltd (NUCOR) is responsible for nuclear research and for waste management.

NUCLEAR FUEL CYCLE

The country has reasonably assured uranium resources of 313,000 tU and a mining/milling capacity of about 5,800 tU/yr (1983). In addition, South Africa has developed its own uranium enrichment process, is operating an enrichment pilot plant and has scheduled construction of a semi-industrial scale plant (300 tSWU/yr) for completion in 1986-1987. NUCOR also has a small UF_6 conversion plant in operation. Eventually, the nation will be dependent upon foreign fuel suppliers only for fabrication and, if required, could develop fabrication capability.

The country has no plans for spent fuel reprocessing, but plans are being made for treatment and disposal of reactor waste. Spent resins will be mixed with concrete and encapsulated in thick-walled concrete drums. The waste will remain at the reactor site until NUCOR has a disposal area ready.

Construction of a nuclear waste repository for LLW and ILW is to begin in late 1984. The site, located in the Vaalputs district of Namaqualand in Cape Province, is expected to be commissioned in about three years.

SPAIN

Spain has three PWRs, one BWR and one GCR installed and had planned, under the previous government, to have an installed nuclear capacity of 12.4 GWe by 1990. The present government, however, has set a limit of 7.5 GWe as of 1992. The Spanish nuclear industry has been heavily dependent upon foreign fuel cycle services, but is moving toward self-sufficiency in this area.

ELECTRIC POWER DATA

Electricity Production

1981: 111.2 TWh--34.5% oil/gas, 35.5% solid fuels, 20.9% hydro, 9.1% nuclear

1982: 116.7 TWh--12.0% nuclear.

Nuclear Power

First operating power plants: 153 MWe PWR (1969); 440 MWe BWR (1971); 480 MWe GCR (1972)

Projection: 1984--3.7 GWe; 1990--7.5 GWe; 2000--10.2 GWe.

ORGANIZATION

Nuclear activities in Spain are controlled by the Government through the Nuclear Energy Agency (JEN), now primarily an R&D organization; EMPRESA, a fuel cycle services company; the Nuclear Safety Council, safey and licensing; and ENRESA, a waste management company. JEN has laboratory facilities in Madrid and is building a new research center at Soria.

NUCLEAR FUEL CYCLE

Reasonably assured uranium resources are estimated at about 20,000 tU, and the annual mining/milling capacity is about 150 tU. Enrichment needs are met through an 11.1% interest in the EURODIF enrichment plant in France, a contract with the USSR for 8,000 tSWU, and a number of enrichment contracts with the US. A fuel fabrication plant started up in 1983.

Spain gained reprocessing experience in the late 1960s through construction and operation of a pilot plant designed to handle MTR fuels, and was moving toward construction of a commercial plant. The government has now adopted a once-through fuel cycle for LWR fuel, however, and intends to dispose of spent LWR fuel directly in a geologic repository. The AR spent fuel storage pools, largely because of dense racking, have capacities equivalent to 7 to 16 years of reactor operation. Interim storage needs are to be met with independent dry-storage facilities, located at the proposed repository site or at the reactor sites.(47)

LLW/ILW is stored at reactor sites or in an abandoned uranium mine located in the Sierra Albarrana in Cordoba Province, southern Spain. Authorities are considering enlargement of the Cordoba facility and the construction of other LLW/ILW repository sites. For disposal of spent fuel, research is focusing on salt and granite formations, with the objective to have an operating repository in place about 2005-2010.

SWEDEN

Sweden has seven BWRs and three PWRs installed, and two BWRs under construction. Present nuclear power policy, mandated by a majority of the voters in a March 1980 referendum, calls for completion of a total of 12 power stations (9.4 GWe) by 1985-86. Thereafter, no growth in nuclear power is planned. Currently, fuel cycle plans are based primarily on the once-through cycle, although a small quantity of spent fuel is to be reprocessed in foreign plants.

ELECTRIC POWER DATA

Electricity Production

1981: 102.7 TWh--57.8% hydro/geothermal; 36.8% nuclear; 4.7% oil; 0.7% solid fuels

1982: 95.2 TWh--39.2% nuclear.

Nuclear Power

First operating reactors: 440 MWe BWR (1972); 800 MWe BWR (1975)
Projection: 1984--7.3 GWe; 1990--9.4 GWe; 2000--9.4 GWe.

ORGANIZATION

National law makes the Swedish power utilities responsible to plan and implement the waste management program. The utilities have delegated responsibility for executing waste management activities to the jointly owned Swedish Nuclear Fuel Supply Company (SKBF). The work of SKBF in waste managemnt is supervised by a special governmental body, the National Board for Spent Nuclear Fuel (NAK), which was organized in July 1981. One of NAK's special functions is to administer the waste management program funds that accrue from fees paid by the nuclear power producers. Compliance with governmental stipulations for erecting and operating nuclear facilities is supervised by the Nuclear Power Inspectorate (SKI) and the National Institute of Radiation Protection. Waste management research and development is conducted by Studsvik Energiteknik AB, the Swedish Geological Survey (SGN) and a number of university laboratories.

NUCLEAR FUEL CYCLE

Fuels Production

Reasonably assured uranium resources are estimated at 43,000 tU, but they occur in low-grade shales, and uranium mining is not considered economically or politically feasible at the present time. Hence, nuclear power companies depend upon foreign sources for uranium and enrichment services. Fuel for Swedish-built reactors is fabricated by ASEA-Atom.

Spent Fuel Management(48)

If no change is made in the current Swedish policy that all nuclear power plants are to be removed from service by the year 2010, the entire Swedish program will produce spent fuel containing about 7,000 tU. The utilities and SKBF currently have contracts for foreign reprocessors to treat 870 tU, stipulating the return of the reprocessing waste to Sweden, but Swedish interests are attempting to sell these contracts, since direct disposal of spent fuel is now preferred.

All nuclear power stations, as well as CLAB (Central Temporary Storage Facility) are built on the coast, and spent fuel and radioactive waste are transported by sea. Located near the Oskarshamn nuclear station, CLAB is a cavern mined out of granite bedrock. It lies beneath 30 m of rock, is designed for wet storage of up to 3,000 tU of spent fuel as long as 40 years, and is sited to allow expansion to 9,000 tU if needed. It also is designed to store canisters of HLW glass. Scheduled for commissioning in early 1985, CLAB is designed for a life of 60 years.(49)

WASTE MANAGEMENT(50)

Reactor waste and other non-high-level materials are immobilized in cement or bitumen and improved waste forms and processes are being developed at a number of sites. Reactor waste is now stored at reactor stations in facilities expected to be full by the end of the 1980s, but SKBF plans to have a central repository ready to receive waste by 1988. The repository will be located offshore in the Forsmark area, under at least 50 m of cover rock and 6 m of water. The offshore location is proposed to assure: the unlikelihood of future inadvertent human intrusion; a low hydraulic gradient; and dilution into the Baltic, should a leak develop. The repository will be mined from onshore.

Deep geologic disposal in a crystalline rock repository at a depth of 500 m is planned for three types of "waste" materials: vitrified HLW; packaged spent fuel; and low- and intermediate-level reprocessing waste, immobilized in concrete or bitumen. All three are to be kept in temporary storage for about 40 years: HLW and spent fuel to allow reduction in the heat and radiation loads on the repository; other reprocessing waste to await construction of the repository. The present target is to have a repository for HLW and spent fuel in operation by 2020.

The HLW glass logs are to be encapsulated in a layer of lead and an external shell of titanium. The spent fuel rods are to be packaged in copper, the interstices being filled with either lead or copper. Further protection for the packages will be provided by a layer of compacted bentonite.(48)

Sweden has extensive areas of crystalline rock formations (gneiss, granite and gabbro) which form part of the Baltic Shield. All field investigations during the 1980s are concerned with geophysical characterization of selected areas where the rock appears suitable for a repository site. During the last four years, geological and hydrogeological investigations in deep boreholes have been made in three sites on the East Coast.(15)

SKBF is managing an extensive R&D program which includes laboratory and field studies of waste form properties, safety and environmental effects, geological and hydrogeological characteristics, radionuclide migration, etc. An important part in the program has been played by the in situ studies in the Stripa Mine in Central Sweden--studies which were conducted for a time as a joint USDOE-SKBF project and which are currently carried out as a multinational cooperative project, coordinated by the OECD/NEA.

SWITZERLAND

Three PWRs and one BWR have been built in Switzerland, a second BWR is under construction, and the utilities want to install additional nuclear capacity. The federal government is pro-nuclear, but has encountered much public opposition to requests for approval of specific power plant sites, and the future of nuclear power is in doubt. Furthermore, federal law now requires nuclear utilities to establish a project guaranteeing the long-term safety of waste management and disposal before any new reactor project can receive a general permit. The Minister of Energy has stipulated that if a satisfactory project is not established by December 31, 1985, the existing plants may lose their operating licenses.

The Swiss nuclear utilities have selected a fuel cycle based on foreign reprocessing, with recycle of plutonium to either LWRs or FBRs, but are also evaluating a once-through fuel cycle and disposal of spent fuel.

ELECTRIC POWER DATA

Electricity Production

1981: 52.7 TWh--69.2% hydro, 28.8% nuclear, 1% oil/gas.

Nuclear Power

First operating reactors: 350 MWe PWR (1969); 320 MWe BWR (1972)

Projection: 1984--2.9 GWe; 2000--3.4 GWe.

ORGANIZATION

Several agencies in Switzerland have major roles in nuclear fuel and waste management: the Federal Institute for Reactor Research (EIR) at Würenlingen, waste management R&D; the National Cooperative Association for the Storage of Radioactive Waste (NAGRA), development and construction of repositories; Lucens Studies Consortium (CEL), intermediate storage of spent fuel and reprocessing wastes; and the Nuclear Energy Inspectorate, licensing of repositories.

NUCLEAR FUEL CYCLE

Switzerland produces no uranium; the utilities purchase their fuel from foreign suppliers and have contracted with COGEMA (France) and BNFL (UK) for reprocessing services. Under contracts signed before 1980, BNFL and COGEMA will keep the reprocessing waste. Under later contracts, the reprocessors have the right to return reprocessing waste to Switzerland.

Authorities estimate that adequate AR storage capacity is available until the mid-1990s, with COGEMA and BNFL accepting spent fuel for storage and all operating reactor pools equipped with dense storage racks. CEL is expected to apply in 1984 for a general permit for a combined AFR storage facility for spent fuel, vitrified HLW and other reprocessing waste. This facility, using metal dry storage casks, is expected to be operational by 1992.

WASTE MANAGEMENT

Waste Treatment

Each nuclear power plant has a conditioning facility in which waste is incorporated in bitumen or cement. Combustible waste from power stations, hospitals, industry and EIR research operations is burned in a high-temperature incinerator at EIR, and EIR is installing an acid digestion rig for plutonium-contaminated waste. Waste treatment R&D includes studies of improved low- and intermediate-level waste forms and techniques to evaluate the HLW glass returned from foreign reprocessors.

WASTE DISPOSAL(50-52)

Authorities have decided to build two geologic repositories: an intermediate-depth facility for terminal storage of LLW and ILW; and a deep geologic facility, designed to store about 1000 m^3 of HLW glass, previously cooled for 30 years.

For HLW, highest priority is given to crystalline rocks underlying the country and at an accessible depth in Northern Switzerland. On the basis of geological criteria, NAGRA has selected an area of about 1000 km^2 for further characterization and is progressing with a program to drill twelve boreholes, exploring the granite basement rock at depths up to 2,500 m. This work is supplemented by geophysical and geodetic surveys, hydrogeological analysis of springs and aquifers in the area, seismic investigations and studies of radionuclide migration. NAGRA also operates an underground laboratory in a granite formation at Grimsel Pass in the Alps, developing methods for the study of rocks in deep boreholes and other in situ tests.

TAIWAN

Taiwan (Republic of China) has four BWRs commissioned, two PWRs under construction, and the Government considers the continued development of nuclear power capacity as the best avenue to the desired growth in electrical power production.

ELECTRIC POWER DATA

Electricity Production(52)

1982: 40.9 TWh--48% oil, 30% nuclear, 12% hydro, 10% coal

2000: 110 TWh--53% nuclear.

Nuclear Power

First operating power plants: 604 MWe BWR (1978); 907 MWe PWR (1984)

Projection: 1984--3.1 GWe; 1990--4.9 GWe; 2000--8.7 GWe.

ORGANIZATION

Nuclear power plants in Taiwan are government-owned and operated by Taiwan Power (Taipower), generally depending on foreign vendor organizations for technical help. The Atomic Energy Council (AEC) has functions similar to those of the USNRC, but also is responsible for waste disposal. Research in the nuclear field is handled by the Institute of Nuclear Energy Research (INER).

NUCLEAR FUEL CYCLE

The government plans to develop LWR fuel fabrication capability and is seeking foreign technology. Taipower's strategy is to develop a fuel assembly plant, a fuel hardware plant, a UO_2 pellet plant and finally, UF_6 conversion capability. A decision on domestic reprocessing is to be made by 1985-1986.

Reactor waste is to be transported in 50-gallon drums to the new National Waste Storage facility on Orchid Island, off Taiwan's Southeastern coast.

UNITED KINGDOM

The first nation to install commercial nuclear power plants, the United Kingdom (UK) has a long-standing commitment to this source of power. The country's commercial power reactors are all gas-cooled and graphite-moderated, but the government pursued an advanced LMFBR test program for many years and now plans to build at least one commercial PWR.

Great Britain has built two generations of gas-cooled reactors: the GCR, fueled with Magnox-clad uranium metal, and the AGR, fueled with SS-clad UO_2. At the end of 1983, there were 26 GCRs, 10 AGRs, and one demonstration LMFBR operational; four AGRs are under construction.

Spent fuel and waste management strategy calls for reprocessing as rapidly as plant capacity permits, vitrification of HLW, long-term interim storage of HLW glass, and shallow-land burial or sea-dumping of LLW and ILW. Authorities expect to build a repository at some time, but have decided that this is not an urgent matter.

ELECTRIC POWER DATA

Electricity Production

1981: 277.7 TWh--74.4% solid fuels, 13.7% nuclear, 9.9% oil/gas, 2% hydro.

Nuclear Power

First operating power plants: 50 MWe GCR (1956), 625 MWe AGR (1976), 250 MWe FBR (1976

Projection: 1984--9.4 GWe; 1990--10.4 GWe; 2000--13.6 GWe.

ORGANIZATION

The fuel cycle/waste management organization is quite complex: the United Kingdom Atomic Energy Authority (UKAEA) is, in general, responsible for nuclear research; the Department of the Environment (DOE) has the charter for developing waste management strategy and for coordinating waste management R&D; British Nuclear Fuels Limited (BNFL) handles the commercial fuel cycle for the British nuclear utilities and for foreign customers; and the Nuclear Industry Radioactive Waste Executive (NIREX) attends to the disposal of LLW and ILW. These organizations are supported by a variety of regulatory, safety and research agencies, e.g., the National Radiation Protection Board (NRPB) and the Nuclear Installations Inspectorate, which handle radiation protection and licensing, respectively, and the UKAEA research establishments at Harwell, Risley, Dounreay, Springfields and Sellafield. Power-generating nuclear plants are owned and operated by the Central Electricity Generating Board (CEGB), the South of Scotland Generating Board, and BNFL. The reactor operators are responsible for unloading spent fuel from the reactors, storing it at the reactor site and transporting it to the reprocessing plant at Sellafield.

NUCLEAR FUEL CYCLE

The United Kingdom has an extensive commercial fuel cycle program, based on the concept of recovering plutonium for recycle to an LMFBR system. Either directly or through subsidiaries, BNFL is involved in uranium conversion and enrichment, uranium fuel fabrication, reprocessing of domestic and foreign fuels, and transport of spent fuels from reactors to the reprocessing plant.

Fuels Production

Great Britain is currently not a uranium producer, although limited mining has occurred in the past and a number of private and foreign companies have a continuing interest in evaluating the uranium production potential.

BNFL fuels production activities include: uranium enrichment through a gaseous diffusion plant and the Urenco gas centrifuge plant, both at Capenhurst; uranium conversion; fabrication of fuels for power reactors; and MOX fuel fabrication in plants at the Sellafield Works.

Spent Fuel Management

BNFL handles spent fuel from three types of reactor: GCR, AGR and LWR. GCR fuel rods, uranium-metal-clad in a magnesium alloy (Magnox) sheath, are subject to corrosion under pool storage conditions and are, in general, reprocessed as soon as possible after discharge from the reactor. (GCR fuels from the Wylfa power station have been kept for over four years in a dry storage vault without deterioration.) AGR and foreign LWR fuels are being stored until the new THORP reprocessing plant is completed, ca. 1990.

Through its nuclear weapons program, the United Kingdom has been reprocessing spent fuel since 1952. To date, four spent fuel reprocessing plants have been built and operated: two large plants at Sellafield (formerly designated Windscale) for military and GCR fuel and two small plants at Dounreay, Scotland, for FBR fuel. A headend plant for oxide fuel was added to the

Sellafield complex and operated briefly in the early 1970s. Through 1980, the Sellafield plants had reprocessed about 20,000 t of Magnox fuel from British GCRs.

A new facility for oxide fuels (THORP) is under construction, to fulfill BNFL's commitments to foreign customers and to treat the UK's AGR and PWR oxide fuel. The THORP complex will include a 1000-tU spent fuel storage pond complex for LWR and AGR fuel, a 600 tU/yr reprocessing plant, and fuel receiving/handling and waste treatment facilities. Present production commitments for THORP total 6,000 tU: 3,000 tU for the UK Electricity Generating Boards; 1,600 tU for Japan; and 1,400 tU for other customers. Reprocessing contracts have been negotiated on the basis that customers bear a share of capital and operating costs, in proportion to the quantity of fuel covered by their contract, and that non-UK customers take back the radioactive waste associated with their spent fuel.

So far as has been practical, reprocessing plants have been designed to allow operation of the highly radioactive sections of the plant for many years without maintenance. This has meant providing redundant process lines; placing equipment with moving parts outside the biological shield and with high-integrity drives through the shield; and placing other sections of the plant in shielded areas external to the main structure where they could be decontaminated quickly and then be accessible for direct maintenance.

A major effort continues to develop and demonstrate the fast reactor fuel cycle. The program includes reprocessing R&D at Dounreay and Harwell; operation of a small FBR fuel reprocessing plant at Dounreay, which treats spent fuel for the Prototype Fast Reactor (PFR); and fabrication of new PFR fuel from recycled plutonium at the Sellafield MOX fuel fabrication plant.

WASTE MANAGEMENT(53)

Current waste management strategy assumes: vitification of HLW in a French-technology plant under construction at the Sellafield site; engineered storage of HLW glass for 50 years or more, until a repository is ready; disposal of LLW/ILW by shallow-land burial or by ocean-dumping; and development of geologic and deep ocean waste disposal technology, with indefinite deferral of any decisions concerning siting or construction of a repository.

Waste Treatment(54)

The UKAEA and BNFL had a rising-level, in-pot vitrification process (FINGAL-HARVEST) in development for several years at Harwell and Risley, with nonradioactive pilot-scale studies and preparations for a radioactive pilot plant, a cold full-scale prototype, and a commercial demonstration plant. The effort was supported by a variety of product characterization studies and other laboratory work. BNFL has chosen the French AVM process for the Sellafield vitrification plant, but work continues on second-generation processes such as the ceramic melter and a technique that depends on the use of microwave heating for calcination and melting.

Considerable effort is devoted to the treatment and immobilization of non-high-level waste: volume reduction, fixation and characterization of TRU waste and fuel cladding hulls; treatment of reactor waste; incineration; control and storage of volatile radionuclides; spent solvent cleanup and disposal; and fixation of nuclides in various matrices.

Waste Disposal

Low-level liquid and gaseous effluents from nuclear plants are diluted and after treatment dispersed in the environment to ensure compliance with discharge regulations. Low-activity solid waste (lightly-contaminated protective clothing, tools, and other trash) is placed in shallow trenches near the Sellafield site, and solid waste of slightly higher activity levels is packaged and dropped into the ocean under OECD/NEA surveillance. All higher-activity waste is held in storage, pending the installation of treatment plants and terminal disposal facilities. The government may decide to provide geologic isolation for ILW, perhaps in an existing mine.(55)

Improved techniques for packaging of solid LLW for sea-dumping are under investigation at Harwell and Sellafield, and various options have been evaluated for disposal of high-level and alpha-bearing waste. Applications for approval of exploratory drilling at a number of sites, in granite, clay, and interbedded clay-salt formations, were submitted by the Institute of Geologic

Sciences (IGS), but local opposition prevented any drilling activity except in Northern Scotland, near the Dounreay site. In late 1981, the government decided to plan for long-term (50 years or longer) engineered storage of HLW glass prior to placement in a repository. This decision removed the urgency to seek and develop an actual repository site for disposal of heat-generating waste, and applications for exploratory drilling programs for site characterization were cancelled.

Decontamination and Decommissioning (D&D)

Current policy is to decommission nuclear facilities at the end of their useful lives to make space and buildings available for new nuclear programs. In implementing this policy, CEGB and UKAEA engineering personnel are carrying out an active R&D program, including D&D projects, studies of design criteria for new facilities to accommodate their eventual decommissioning, and radiological assessments.

UNITED STATES

For many years, nuclear power received widespread popular and governmental support and US nuclear industry led the world in domestic application and foreign export of nuclear technology. Recent years have seen an erosion of popular support, cancellations of nuclear plant orders, and termination of construction projects actually in progress. In 1979, utilities were planning to have between 255 and 295 GWe of installed nuclear power capacity by the year 2000. Today, the projection for the year 2000 is for about 114 GWe installed nuclear capacity.

US nuclear power plants are nearly all LWRs, with an approximate 2:1 mix of PWRs versus BWRs. The country has also conducted major LMFBR and HTGR development programs.

Current civilian fuel cycle activities include all phases except reprocessing: uranium mining, milling and enrichment; fabrication of UO_2 and MOX fuels; interim spent fuel storage; transportation; and conditioning of reprocessing waste.

ELECTRIC POWER DATA

Electricity Production

1981: 2,472.7 TWh--52% solid fuels, 24% oil/gas, 12% nuclear, 11% hydro.

Nuclear Power

First operating power plants: 207 MWe BWR (1960); 175 MWe PWR (1961);
330 MWe HTGR (1979); 860 MWe LGR (1966)

Projection: 1984--65.6 MWe; 1990--107.0 MWe; 2000--114 MWe.

ORGANIZATION

Federal government interests in the civilian nuclear power area are administered by the Department of Energy (DOE: R&D, uranium enrichment, waste disposal), the Nuclear Regulatory Commission (NRC: regulation and licensing) and the Environmental Protection Agency (EPA: environmental protection criteria). Commercial power generation, fuel fabrication, reprocessing and waste treatment activities are the responsibility of private industry. Fuel cycle and waste management R&D is conducted primarily by contractor organizations operating DOE's National Laboratories, repository projects, and the nuclear defense materials program. Many universities and privately-owned companies support the commercial fuel cycle and waste management R&D effort.

NUCLEAR FUEL CYCLE

National policy is based on the assumption of a closed fuel cycle, with reprocessing by private industry and recycle of plutonium to breeder reactors. After three attempts to establish viable commercial reprocessing ventures, industry sees little economic incentive to try again without government support and the future of civilian fuel reprocessing in the United States is uncertain.

Strategy for the back-end of the commercial nuclear fuel cycle is shown conceptually in Figure 1. The basic intent is to hold the fuel in storage at the reactor until it can be reprocessed, immobilize the reprocessing waste and place the HLW glass and TRU waste packages in a geologic repository. As an alternative, if commercial reprocessing services do not become available, provision for the direct disposal of spent fuel is made. The Nuclear Waste Policy

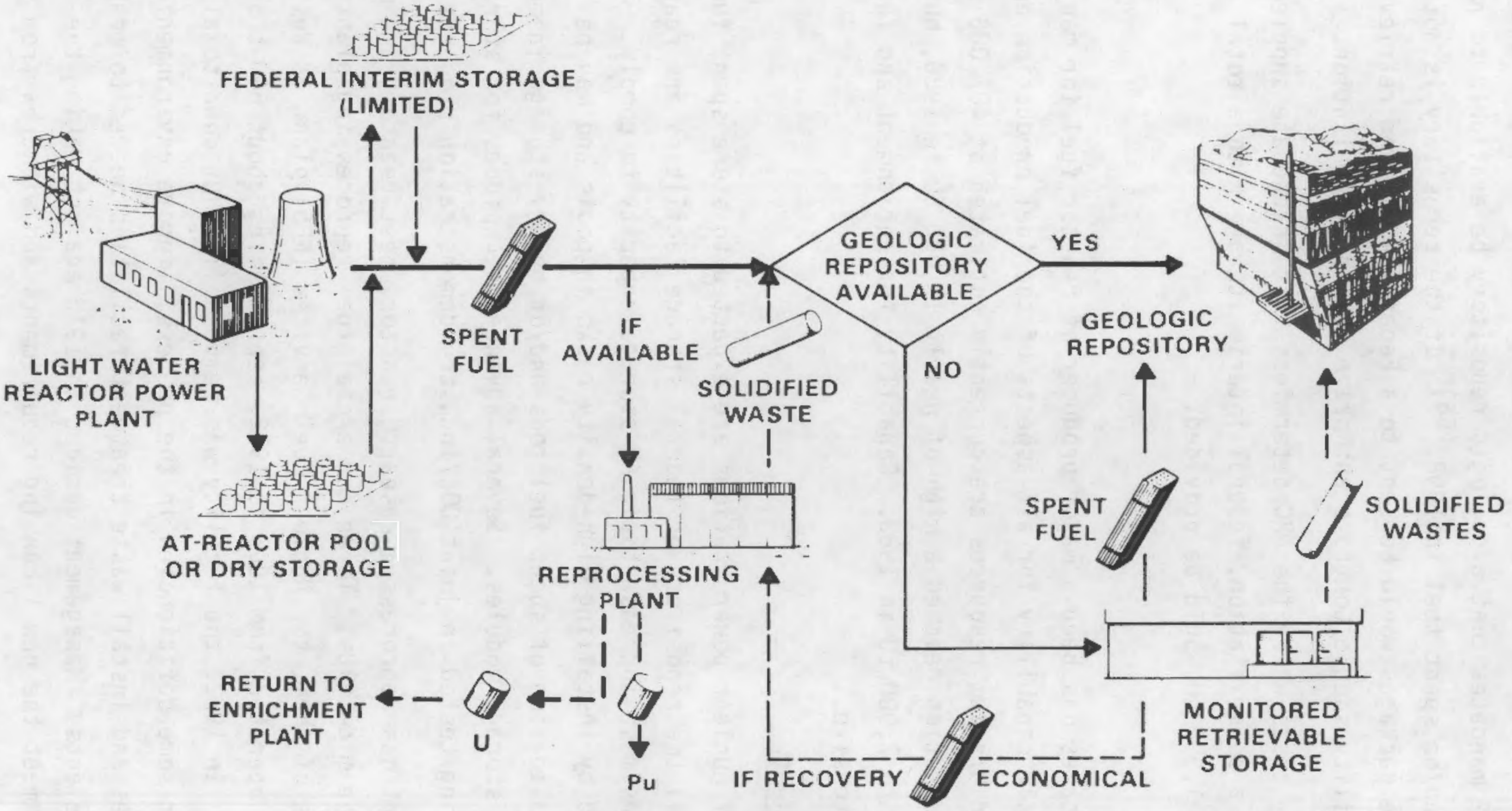

FIGURE 1. Commercial Nuclear Fuel Cycle

Act (NWPA) of 1982 mandates that a geologic repository be available to receive immobilized HLW and/or spent fuel in 1998.(56) If the repository is not ready in time, the waste packages would be sent to a Federal monitored retrievable storage (MRS) facility should Congress authorize such an installation.

For emergency cases where the NRC determines that inadequate supplemental storage exists at a power station, federal interim storage with a total capacity not to exceed 1,900 tU would be provided.

Fuel Production

The United States has been a major producer of reactor fuel for many years, with domestic capability for all aspects of the fuel production process. Reasonably assured uranium resources are currently estimated at 407,000 tU. Annual uranium production reached a high of nearly 17,000 tU in 1980, but since then has declined to 7,900 tU in 1983. Capability for enrichment and fuel fabrication is extensive.

Spent Fuel Management

The owners of nuclear power stations are expected to store spent fuel at reactor sites until the repository or federal storage facilities are ready, and some power stations must increase their AR storage capacity to comply. This is being accomplished by installing high-density racks in pools and may be augmented by consolidation of spent fuel rods and/or by dry storage in metal casks or concrete storage modules. Several advanced techniques for storing spent fuel are being tested in joint DOE/industry demonstration projects.

The government has reprocessed research reactor, test reactor, and military fuel since the mid-1940s. Three commercial fuel reprocessing plants have been built and one of them, the Nuclear Fuel Services (NFS) plant at West Valley, New York, operated from 1966 to 1972, reprocessing about 640 t of fuel during that time. In 1972, the facility was temporarily shut down to allow expansion, correct some deficiencies in the process, improve environmental-protection features and install waste treatment facilities needed to meet new regulatory requirements. Management decided in 1976 against making the investment necessary to meet the new licensing requirements and withdrew from the reprocessing business. The reprocessing facility is currently being decontaminated and preparations are in progress to condition and remove the reprocessing waste.

Construction of the Barnwell Nuclear Fuel Plant (BNFP) in South Carolina, a nominal 5 tU/d facility, started in 1971. In 1977, the project had reached the point of extensive cold-testing, when the federal government placed a moratorium on commercial fuel reprocessing. Faced with the moratorium and a need to build facilities for plutonium conversion and HLW vitrification, the owner eventually elected to decommission the plant. Even though the current national administration has discontinued the moratorium, efforts to find a new industrial sponsor have not been successful.

The Midwest Fuel Recovery Plant at Morris, Illinois, with a design throughput of 300 tU/yr, was originally scheduled for startup in 1972. The plant employed major departures from the typical Purex-TBP process, and cold-testing revealed several process problems. In 1974, the owner concluded that the plant was inoperative and necessitated modifications requiring several years and costing in excess of $100 million to become operational. The decision was made to abandon the effort.

In addition to the principal commercial and defense reprocessing programs described, extensive nonradioactive and radioactive R&D has been conducted at DOE laboratories. A major demonstration of pyrochemical reprocessing was undertaken at the EBR-II facility of the Idaho National Engineering Laboratory in the early sixties. Also, reprocessing of LWR fuel was a main part of the demonstration of the Nuclear Waste Vitrification Project conducted at the Hanford Site in 1976-79.

Current fuel reprocessing R&D studies center in the Consolidated Fuel Reprocessing Program (CFRP), under the direction of Oak Ridge National Laboratory, with the development of technology for reprocessing spent LMFBR fuel being its principal objective. The major activity in the CFRP is the associated Breeder Reprocessing Engineering Test (BRET), a joint effort between Hanford Engineering Development Laboratory and Oak Ridge National Laboratory. In another phase of the CFRP, research and development activities in HTGR fuel reprocessing technology are being conducted at General Atomic Company.

WASTE MANAGEMENT

Waste Treatment

The United States has pioneered the development of immobilization processes for HLW and has provided the base technology for the calcination and vitrification techniques being applied in Europe and Japan. R&D effort emphasizes adaptation of the liquid-fed ceramic melter (LFCM) process to defense waste from the Savannah River and Hanford reprocessing plants and to civilian power waste from the West Valley project. LFCM plants are currently being designed for Savannah River and West Valley.

Various types of treatment processes (compaction, incineration and acid digestion of combustible materials; decontamination and melting of fuel cladding hulls; and immobilization of residues in different media) have been developed and demonstrated for plutonium-contaminated materials.

Treatment employed for LLW varies from generator to generator, but generally differs little from those used in other countries. At commercial reactors, low-level liquid wastes are commonly treated by evaporation and ion exchange, with the clean liquid recycled or released and the concentrate fixed. Cement is the most common fixation agent, urea-formaldehyde is being discontinued and bitumen is beginning to be adopted at some facilities. Compactors are usually employed for solid waste volume reduction at power reactors.

At fuel cycle supporting facilities, e.g., fuel fabrication plants, fuel reprocessing centers, research complexes, etc., chemical conditioning, evaporation, and ion exchange are commonly used to decontaminate low-level liquid waste prior to its release to the ground or a nearby waterway. The concentrate may be kept onsite or packaged (if suitably dry) for transfer to a shallow-land burial ground. At fuel fabrication plants, the concentrates are collected in lagoons for eventual recovery of the sludges and transfer to a shallow-land disposal area. Fuel reprocessing plants and associated research centers collect concentrates in tanks for handling with their high-level waste. Low-level solid waste is generally compacted, but incineration is not used extensively. One exception is the low-level waste incinerator recently put into operation at the Savannah River Site.

Waste Disposal

Oisposal of LLW by shallow-land burial is universally used. Sea-dumping took place between 1946 and 1970 but has been discontinued. Commercially-generated and institutional waste is disposed of at three commercial burial sites. LLW, generated during weapon material operations, is disposed of by shallow-land burial at the generation site; in one instance (ORNL), radioactive waste is injected as a grout into the underlying geologic strata.

From 1973 until recently, US policy required all waste contaminated above 10 nCi TRU/g be stored retrievably for eventual disposal in a geologic repository. As a result, major DOE sites have built interim storage facilities consisting of earth-covered berms or tile holes. The limit has now been raised to 100 nCi/g.

It is planned to place TRU waste from weapon material production activities in the Waste Isolation Pilot Plant (WIPP).(57) This facility is a salt mine repository located in the State of New Mexico. Two shafts have been constructed, and underground mining is under way. Startup of the facility is scheduled for the fall of 1989.

The current overall program strategy for disposal of civilian HLW or spent fuel is defined in the Nuclear Waste Policy Act of 1982. This act established rules for siting, licensing, constructing and operating geologic repositories for disposal of HLW. It also established a waste fund to be collected from the utilities and a time table, leading to receipt of waste for disposal, beginning in 1998. The act calls for two repositories, the first to be sited in one of nine potentially acceptable sites, situated in different rock formations: bedded salt, salt domes, basalt, and tuft. Potential sites in crystalline rock formations are to be considered for the second repository.

The repository deployment program is supported by extensive research and development: waste form and waste package design and characteristics; characterization of potential repository sites; radionuclide transport studies; safety and environmental assessments; repository design studies; and operation of several pilot research projects.(58)

INTERNATIONAL AGENCIES

Several international organizations, with somewhat overlapping memberships, devote major attention to nuclear fuel cycle and radioactive waste management problems. Common objectives are to promote cooperation and information exchange among members, identify and minimize duplication of R&D effort, and develop information for the assessment of radioactive waste management practices.

COMMISSION OF THE EUROPEAN COMMUNITIES

The Commission of the European Communities (CEC) is the agency which administers the cooperative economic and energy-related activities initiated under the European Coal and Steel Community, the European Economic Community, and Euratom. The Member States, which are also NEA members, include:

Belgium
Denmark
France
Germany (FRG)
Greece
Ireland
Italy
Luxembourg
Netherlands
United Kingdom

The European Coal and Steel Community (ECSC) was created in 1951 to pool the coal and steel production of the six member states. In 1957 the European Economic Community (EEC) and the European Atomic Energy Community (Euratom) were formed by the same six Member States. In 1967, the ECSC, EEC, and Euratom commissions were merged into the Commission of the European Communities (CEC), which assumed the responsibility to formulate and implement policy for the three communities.

Euratom objectives were to: develop nuclear research capability; establish nuclear safety standards; encourage the development of nuclear power; and exchange information and capital for nuclear enterprises among the member states. Euratom resources include the Joint Research Centre (JRC) with research establishments at: Ispra, Italy (JRC-Ispra); Mol, Belgium (Central Bureau for Nuclear Measurements); Petten, Netherlands (Petten CCR); and Karlsruhe, FRG (European Institute for Transuranium Elements, EIT).

The provisions of the original treaty establishing Euratom are still in effect, and Euratom objectives for the cooperative development of nuclear energy guide a major CEC program.

Supported by funds received through taxing the Member States, CEC contributes significantly to two types of waste management R&D programs: the "direct action" programs carried out at Euratom JRC sites, primarily the Ispra and Karlsruhe laboratories; and the "indirect action" programs conducted by the Member States under a joint-funding arrangement in which CEC pays up to 50% of designated project costs. Direct action programs are generally planned, budgeted, and approved on a 4-year cycle, indirect action programs on a 5-year cycle.

Results of CEC-sponsored R&D programs are disseminated freely among Member States, but CEC approval is required for transmitting such information outside the community.

COUNCIL FOR MUTUAL ECONOMIC ASSISTANCE

The Council for Mutual Economic Assistance (CMEA) is the counterpart of the OECD for countries with centrally-controlled economies. The mission of the CMEA is to promote economic and industrial cooperation among Member States (Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Mongolia, Poland, Rumania, USSR, and Yugoslavia). The CMEA has a Standing Commission on the Use of Atomic Energy for Peaceful Purposes, which holds meetings to review national waste management programs and defines areas for additional cooperation.

INTERNATIONAL ATOMIC ENERGY AGENCY

The International Atomic Energy Agency (IAEA) is an independent organization which belongs to the United Nations family and embraces developing and developed countries, as well as nations having either privately or centrally controlled economic systems. Its membership comprises 110 nations. Detailed work of the Agency is handled by the Secretariat, with extensive help from technical committees and consultants. The committees are generally established on an ad hoc basis, with a specific short-term assignment, although there are technical committees which work on a continuing basis.

The IAEA has a number of specific objectives for its radioactive waste management programs:

- disseminate up-to-date information concerning safe methods for managing radioactive waste and maintaining acceptable radioactivity levels in effluents from systems handling radioactive materials
- coordinate and/or promote the development of technology for safe management of radioactive waste
- issue safety guidance on all aspects of radioactive waste management
- assess the consequences of releases of radionuclides into the environment from nuclear activities
- provide, upon request, technical advice, training, and assistance to Member States
- conduct or participate in studies considering regional or worldwide planning of the nuclear fuel cycle.

These objectives are met primarily by organizing and conducting various meetings, usually among experts from Member States, and by preparing and publishing reports. The meetings include: Conferences and Symposia, often cosponsored with another organization such as the NEA or CEC; Advisory Groups, convening to review and advise on program content, methods of conducting programs, etc.; Technical Committees which review agency programs or reports in depth; consultants brought in from Member States to perform a specific technical task such as preparing or modifying a technical report; Coordinated Research Program meetings to coordinate the research in a specific technical area among various institutes; and Review Groups, assembled occasionally to review program progress and direction.

OECD NUCLEAR ENERGY AGENCY

The Nuclear Energy Agency (NEA) is a semiautonomous subsidiary of the Organization for Economic Cooperation and Development (OECD). Membership, primarily European with a sprinkling of other nations with privately-controlled economies, includes:

Australia
Austria
Belgium
Canada
Denmark
Finland
France
Germany (FRG)
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

(New Zealand and Yugoslavia cooperate in certain projects.)

The work of NEA is carried out under the authority of the OECD Council and under the general guidance of the Steering Committee for Nuclear Energy. The Steering Committee is in turn assisted by other committees and working groups of specialists. A small Secretariat functions by assisting the Steering Committee and its subsidiary committees and working groups.

Early in its existence, the European Nuclear Energy Agency (forerunner of the NEA) fostered the establishment of several joint projects by groups of interested Member States. Notable examples of this are the Eurochemic Fuel Reprocessing Demonstration Plant at Mol, Belgium, built and operated by 13 countries; the Halden Reactor Project; and the Dragon High-Temperature Reactor Project.

In the waste management field, ENEA and then NEA were, until 1975, primarily involved in collecting and disseminating information for Member States, occasionally sponsoring or cosponsoring international symposia and seminars, and preparing specific documents on radioactive waste management practices. In 1975, NEA established its Radioactive Waste Management Committee (RWMC) with the assigned purpose of initiating, encouraging, and coordinating cooperative R&D activities among Member States.

Current international projects include:

- Seabed Working Group. Annual meetings have been held since 1976 to review and coordinate activities concerned with the disposal of high-level waste in subseabed formations.
- Stripa Project. Several NEA Member States have joined in an in situ test program, at the Stripa Mine in Sweden, directed at advancing crystalline rock repository technology.

- ISIRS Project. The International Sorption Information Retrieval System (ISIRS), designed to permit the collection and use of worldwide data on radionuclide sorption measurements, has been established at the NEA Computer Center in Saclay, France.

The Executive Group for Research and Surveillance on Sea Disposal of Low-Level Radioactive Waste provides for cooperation among Member States concerning standards, guidelines, and recommendations for dumping treated low-level radioactive waste at sea. Other NEA committees involved with fuel cycle matters include the Committee on Radiation Protection and Public Health (CRPPH) and the Committee on Safety of Nuclear Installations (CSNI).

NEA also interacts with two other OECD bodies in waste management matters: the International Energy Agency and the Environment Committee.

APPENDIX

FUEL CYCLE SYSTEMS

Nine distinct types of nuclear power reactor are either in current commercial use or in the demonstration stage. In a discussion of the fuel cycle, it is convenient to divide them into four major categories, according to fuel type:

1. Reactors fueled with uranium metal or alloys. These include the graphite-moderated, gas-cooled reactor (GCR), built in significant numbers by the UK and France and tried on a one-time basis by several other countries, and the water-cooled, graphite-moderated channel-type reactor (LGR). The US has one LGR (Hanford NPR), while the Soviet Union has built several of them.
2. Reactors fueled with natural or enriched UO_2 fuel. These are found in several versions: the light-water reactor (LWR), cooled and moderated by normal water and in use in large numbers around the world; the heavy-water reactor (HWR), exploited by Canada and in use in several other countries; and two second-generation graphite-moderated reactors, Great Britain's Advanced Gas Reactor (AGR) and the Soviet Union's oxide-fueled LGR.
3. Reactors fueled with PuO_2-UO_2 (MOX) fuel. MOX fuel was developed primarily for fast breeder reactor (FBR) use, but application in LWRs and Japan's HWR has also been demonstrated.
4. Reactors fueled with graphite-matrix uranium/thorium fuel, developed for the high-temperature gas reactor (HTGR).

Selected reactor parameters for a few typical non-US nuclear power stations are listed in Table 1.

Three different types of fuel cycle have been demonstrated:

1. Once-through scheme. Spent fuel is kept in an interim storage facility until it can be disposed of.

TABLE 1. Reactor Parameters--Selected Power Stations(59)

Fuel Type	Reactor Type	Country	Power Station	Fuel		Moderator	Coolant
				Material	Cladding		
U metal and alloys	GCR	France	Chinon 3	Natural U	Mg-Zr	Graphite	CO_2
		UK	Oldbury 1	Natural U	Magnox	Graphite	CO_2
	LGR	USSR	Beloyarsk 2	Enriched U-Mo	Zr-Nb	Graphite	H_2O
Natural and enriched UO_2	AGR	UK	Dungeness B1	Enriched UO_2	SS	Graphite	CO_2
	BWR	FRG	Kruemmel KKK	Enriched UO_2	Zr-2	H_2O	H_2O
	HWR	Canada	Bruce 4	Natural UO_2	Zr-4	D_2O	D_2O
		India	Kalpakkam	Natural UO_2	Zr-2	D_2O	D_2O
		Japan	Fugen	Enriched UO_2 and MOX	Zr-2	D_2O	H_2O
	PWR	France	Paluel 1	Enriched UO_2	Zr-4	H_2O	H_2O
		USSR	Novo-Voronezh 3	Enriched UO_2	Zr-Nb	H_2O	H_2O
			Novo-Voronezh 5		Zr-Nb	H_2O	H_2O
	RBMK	USSR	Smolensk 1	Enriched UO_2	Zr-Nb	Graphite	H_2O
UO_2/PuO_2 (MOX)	FBR	France	Phenix	UO_2/PuO_2	SS	None	Na
Graphite-matrix	HTR	FRG	THTR 300	Enriched $(U,Th)O_2$	Graphite	Graphite	He

2. Thermal reactor recycle concept. Spent fuel is reprocessed, and both the uranium and the plutonium can then be incorporated in new fuel elements for recycle to a thermal reactor.
3. Fast breeder reactor recycle. Spent fuel is reprocessed and the uranium and plutonium recycled to fast breeder reactors.

The annual tonnage of spent fuel discharged from a reactor or reactor complex is a function mainly of the reactor power level, the fuel burnup and the reactor operating efficiency. Estimated annual discharge rates (annual arisings) for the reactors listed in Table 1 are shown in Table 2, along with other spent fuel parameters: weight of a typical fuel element, expected burnup level, and estimated annual spent fuel arisings per GWe of installed capacity.

Table 3 provides an estimate of installed nuclear power capacities, annual spent fuel arising rates and cumulative spent fuel arisings as of the year 2000. Table 4 summarizes waste management strategies for disposal of spent fuel, and civilian fuel cycle activities are listed in Table 5.

TABLE 2. Characteristics of Typical UO_2 Fuels(60)

Characteristics	PWR	BWR	HWR (CANDU)	AGR
Reactor size (MWe net)	1000	1000	540	660
Approximate fuel assembly dimensions (cm)				
Length	320-483	447	49.5	105
Cross-section				
Side (square)	19-23	14-15.3		
Diameter (circle)			8.1-10.3	24
Weight per assembly (kg)				
Total	480-840	250-307	16.6-24.7	83.5
Heavy metal (HM)	122-548	172-194	13.4-19.8	42.7
Pins per assembly	126-331	47-64	19-37	36
Design burnup (GWd/t)	26-40	27.5-30	6.5-8.1	10-25
Fuel enrichment				
Initial % ^{235}U	3.0-4.4	2.5-3.5	Natural (0.71)	2.01-2.55
Final % ^{235}U	0.8-1.26	0.8-1.0	0.205-0.282	0.5-1.2
Total activity (Ci/kg)				
After 150 d	4.6×10^3	3.8×10^3	NA(a)	$1.2\text{-}3.1 \times 10^3$
After 1 yr	2.3×10^3	1.9×10^3	7.9×10^2	$6.1\text{-}15 \times 10^2$
After 10 yr	3.2×10^2	2.9×10^2	8.4×10^1	$1\text{-}2.5 \times 10^2$
Decay heat (W/kg)				
After 150 d	24.3	18.7	NA	4.9-12.4
After 1 yr	10.4	8.2	3.15	2.4-6.1
After 10 yr	2.3	2.2	0.22	0.3-0.7
Calculated fuel discharge, tU/GWe•yr(b)	32-38	38-40	150	49

(a) NA--information not available.
(b) Actual discharge depends on reactor operating efficiency.

TABLE 3. Nuclear Power and Spent Fuel Arisings

			Projections for Year 2000		
Country	Reactor Type[a]	First Commercial Power Plant (MWe)	Nuclear Power Capacity,[a] GWe	Spent Fuel Arisings, tHM[b] Annual	Cumulative
Argentina	HWR	1974 (344)	3.0	525	5,300
Belgium	PWR	1975 (393)	8.0	150	2,800
Brazil	PWR	1982 (626)	4.4	120	1,000
Bulgaria	PWR	1974 (440)	7.8	200	2,500
Canada	HWR	1968 (206)	15.6	2,000	36,000
China	PWR	1987 (300)	10	270	1,300
Cuba	PWR	1987 (440)	1.8	50	420
Czechoslovakia	PWR	1978 (440)	11-14[c]	350	3,800
Egypt	PWR	1990 (900)	2.7	70	360
Finland	LWR	1977 (420)	3.2	85	1,500
France	GCR	1959 (40)	--	--	15,000[c]
	PWR	1967 (305)	61.2	1,280	19,000
	FBR	1973 (233)	1.5		
Germany-East	PWR	1966 (80)	9	270	2,100
Germany-West	LWR	1968 (328)	29.3	750	11,000
	HTGR	1985 (296)	0.3		
	FBR	1987 (280)	0.3		
Hungary	PWR	1983 (440)	4.8[e]	150	1,400
India	BWR	1969 (200)	0.4	18	500
	HWR	1973 (202)	4.0	560	4,400
Israel	LWR	1994 (900)	4.6	110	400
Italy	GCR	1964 (150)	--	--	1,700[c]
	LWR	1965 (260)	6.7	240	1,300
Japan	GCR	1966 (159)	--	--	1,500
	LWR	1970 (341)	47.2	1,400	19,000
	HWR	1979 (149)	0.15		
	FBR	1990 (280)	0.28		
Korea (South)	PWR	1978 (556)	10.5	310	3,200
	HWR	1983 (629)	0.6	70	1,200
Mexico	PWR	1986 (654)	1.3	40	500
Netherlands	LWR	1969 (58)	0.5	15	360
Pakistan	HWR	1972 (125)	0.13	12	290
	LWR	1990 (1,000)	1.0	30	150
Philippines	PWR	1985 (620)	1.2	32	270
Poland	PWR	1989 (465)	5.9	175	1,000
Romania	PWR	1983 (440)	0.44	13	220
	HWR	1986 (700)	6.6[f]	750	8,000
South Africa	PWR	1984 (922)	2.8	115	1,200

TABLE 3. (contd)

			Projections for Year 2000		
			Nuclear Power Capacity,[a]	Spent Fuel Arisings, tHM[b]	
Country	Reactor Type[a]	First Commercial Power Plant (MWe)	GWe	Annual	Cumulative
Spain	GCR	1972 (480)	0.48	60	1,740[c]
	LWR	1968 (160)	9.7	230	2,900
Sweden	LWR	1972 (440)	9.4	275	4,500
Switzerland	LWR	1969 (350)	3.4	110	2,200
Taiwan	LWR	1978 (606)	8.7	260	2,600
UK	GCR	1956 (50)	--	--	30,000[d]
	AGR	1976 (520)	8.2	220	3,600
	PWR		5.1	140	210
	FBR	1975 (250)	0.25		
USA[g]	LWR	1957 (60)	111.5	3,600	58,000
USSR	LGR	1958 (100)	0.9	50	1,500[d]
	Advanced LGR	1973 (1,000)	31.9 (1990)	720	7,400
	PWR	1964 (210)	39.9 (1990)	1,000	4,500
Yugoslavia	PWR	1981 (632)	2.6	70	420

(a) Unless otherwise indicated, nuclear power forecasts were obtained from:
- NUKEM Market Report on the Nuclear Fuel Cycle--6/84," NUKEM GmbH, Hanau, Federal Republic of Germany.
- "AIF INFO News Release," March 31, 1983.

(b) Projections of foreign spent fuel arisings were based on data in the following references, modified by PNL to fit current forecasts of nuclear power capacity:
- Worldwide Spent Fuel Disposition Analysis, Nuclear Assurance Corporation, NAC Report No. C-8023, September 1980.
- Summary of Nuclear Power and Fuel Cycle Data in OECD Member Countries, March 1984, OECD/Nuclear Energy Agency.
- "NUKEM Market Report on the Nuclear Fuel Cycle--6/84," NUKEM GmbH, Hanau, Federal Republic of Germany.

(c) "Czechoslovakia Expands On-Site Storage After Considering Centralized Facility," Nuclear Fuel, October 24, 1983.

(d) The cumulative values for arisings of GCR and LGR (uranium metal) spent fuels do not represent inventories, since this type of fuel is usually reprocessed soon after its discharge from the reactor.

(e) "Hungary's First Nuclear Unit Went On-Line in January," Nuclear News, March 1983, p. 26.

(f) "Rumania Trying to Make Up Lost Time in Installing Nuclear Plants," Nucleonics Week, August 18, 1983.

(g) Projections for spent fuel arisings were taken from the document, "Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/NE-0017/2, September 1983.

TABLE 4. Spent Fuel Management

Country	Reactor Mix	Spent Fuel Management Reprocess	 High-Level Waste Disposal
Argentina	PHWR	Yes--domestic	HLW glass--granite repository
Belgium	LWR	Yes--foreign & domestic	HLW glass--clay repository
Brazil	LWR	Yes--domestic	HLW glass--repository
Bulgaria	LWR		Return spent fuel to USSR
Canada	PHWR	To be determined	Spent fuel or HLW glass--clay repository
Czechoslovakia	LWR		Return spent fuel to USSR
Finland	LWR	To be determined (foreign)	Return USSR fuel to USSR; other spent fuel or HLW glass--granite repository
France	LWR, GCR, FBR	Yes--domestic	HLW glass--repository host rock not yet announced
German Democratic Republic	LWR		Return spent fuel to USSR
Germany, Federal Republic	LWR, FBR, HTGR	Yes--foreign & domestic	HLW glass--salt repository
Hungary	LWR		Return spent fuel to USSR
India	PHWR, LWR	Yes--domestic	HLW glass--crystalline rock repository
Italy	LWR	Yes--domestic	HLW glass--clay repository
Japan	LWR, GCR, HWR, FBR	Yes--domestic	HLW glass--repository host rock to be determined
Korea (ROK)	LWR, PHWR	To be determined	To be determined
Mexico	LWR	To be determined	To be determined
Netherlands	LWR	Yes--foreign	To be determined
Pakistan	PHWR, LWR	Yes--domestic	To be determined

TABLE 4. (contd)

Country	Reactor Mix	Spent Fuel Management Reprocess	 High-Level Waste Disposal
South Africa	LWR	No	To be determined
Spain	LWR, GCR	GCR fuel--foreign LWR fuel--No	Spent fuel--repository host rock to be determined
Sweden	LWR	Small quantities--foreign	Spent fuel and HLW glass--crystalline rock repository
Poland	LWR		Return spent fuel to USSR
Switzerland	LWR	Yes--foreign	HLW glass--granite repository
Taiwan	LWR	To be determined	To be determined
United Kingdom	GCR, AGR, FBR	Yes--domestic	HLW glass--disposal mode not yet determined
USA	LWR, HTGR	To be determined	HLW glass or spent fuel--repository host rock not yet determined
USSR	LWR, LGR, FBR	Yes	HLW glass--repository host rock not announced
Yugoslavia	LWR	To be determined	To be determined

TABLE 5. Civilian Fuel Cycle Activities--Plants Planned or Operating

Country	Uranium Mining and Milling	Uranium Enrichment	Fuels Fabrication	Spent Fuels		HLW Immobilization
				AFR Storage	Reprocessing	
Argentina	X	X	X	X	X	X
Australia	X					
Belgium			X		X	X
Brazil	X	X	X		X	
Canada	X		X	X		
Central African Empire	X					
China (PRC)	X	X	X		X	X
France	X	X	X	X	X	X
Gabon	X					
Germany (FRG)	X	X	X	X	X	X
India	X		X		X	X
Italy	X		X	X	X	X
Japan	X	X	X		X	X
Netherlands		X				
Pakistan		X	X		X	
Spain	X		X	X		
Sweden			X	X		
USSR	X	X	X		X	X
United Kingdom		X	X	X	X	X
USA	X	X	X	X		X

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